COMMERCIAL DIVING: SURFACE-MIXED GAS, SUR-D-O_2, BELL BOUNCE, SATURATION

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Introduction

In the commercial diving world, mixed-gas diving usually begins around 180 fsw and is limited by the U.S. Coast Guard to 300 fsw, except in California OSHA waters, where surface diving to 350 fsw is permitted. It is virtually always sur-D-O_2. To this author's knowledge, no commercial in-water decompression tables exist for mixed gas. Excessively long in-water decompression times would present risks and operational difficulties for the diver.

Decompression Tables and Incidence Rates

In general, three HeO_2 tables are in current commercial usage: the Oceaneering International (OI) Alpha tables, the old American Oilfield Diving (AOD) Company gas tables (also referred to as 50/50 tables), and various modifications of the USN Partial Pressure Tables. Bubble growth analyses of the Alpha's show them to be a relatively safe table, yielding approximately one undeserved bend in nearly 800 dives (as reported by former Corporate Safety Director Terry Overland, on Oceaneering's multi-year experience). There are no data for the Alpha-like AOD tables, yet some report them to be even better than the OI Alpha Tables. This author has used a slightly modified form of these AOD tables for three years in a small commercial company, having no cases of DCI in just over 300 dives. Personal experience with the Ocean Systems modification to the old Navy partial pressure tables resulted in a higher rate of DCS. These tables were again modified by SubSea International using the bubble growth models (Gernhardt/Lambertson/Miller) to eventually yield a safety record equivalent to the Alpha's while having an average of 10 – 15 minutes more bottom time. However, it is enlightening to compare these rates with the one undeserved bend in approximately 1500 decompression dives routinely experienced using commercially modified Navy sur-D-O_2 air tables and one in over 4000 decompression dives using the Lambertsen/Gernhardt/Miller/Beyerstein Next Generation sur-D-O_2 air tables. Using the USN tables as published, both pre-1995 and later, yields an unacceptably high rate of DCS and no commercial company would consider using them unmodified today.

Sur-D-O_2

Surface decompression using oxygen is a technique where the diver performs some in-water decompression stops, comes to the surface exposed to one atmosphere for a limited period, and then is recompressed in a double-lock deck decompression chamber. A decompression mix of 50/50 nitrox is usually employed, specified by the AOD and Alpha tables, for a portion of the in-water decompression, normally beginning at 90 fsw but never deeper than 100 fsw. The use of pure oxygen at 50 fsw and 40 fsw in the water as per older Navy doctrine is now universally no longer practiced in the commercial world. In the deck chamber, common recompression practice is to descend to 50 fsw for 10 minutes breathing oxygen, ascend to 40 fsw where the majority of the decompression takes place, followed by a 10 minute ascent to the surface. Oxygen breathing in the chamber is interrupted by air breaks, usually on a :20 and :05 or :25 and :05 minute schedule.

Bell Bounce Diving

Bell bounce diving was once quite prevalent commercially, being well suited to drill rig intervention diving. This market is now the exclusive province of the ROV world, and commercial bell-bounce diving has disappeared. For normal operations it offers no advantage and requires equipment, crew, and training similar to a full saturation diving system. It may possibly find a use in the scientific world, as it applies to a requirement for limited-bottom time deep dives, matching the scientific mission profile. Depending on depth and duration, the diver enters a saturation decompression mode during his decompression.

Bell bounce diving tables were problematic resulting in many bends. Oceaneering had the Yankee tables and SubSea had the SSM7 tables from Virginia Mason University. Other companies used tables from several sources, Allan Krasburg being one. The tables were all high ppO_2 decompression tables. SSM7's used 0.7 ppO2, modified Bühlmann used 0.8 ppO_2. The divers all hated them as they came out "crispy" from high pulmonary oxygen toxicity.

The drill rig diving arena of the North Sea diving experience, during the mid to late '70's, was responsible for most of the many diving fatalities experienced in those days (See *Requiem for a Diver*, by Jackie Warner, former UK Diving Inspectorate Head). Rig divers came out of dive schools and were immediately employed as commercial divers, not tenders. The limited diving involved with drill rigs meant many days of idleness followed by a deep dive in a hurry. The time pressure was intense. Most of the incidents had root causes in diver inexperience and lack of training, something to consider for the scientific community contemplating this diving mode.

Saturation diving

Saturation diving requires the heaviest resource commitment. First of all, the diving platform, vessel, or barge, has to be large enough in deck space and quarters. It can be anchored if the diving is not too deep, but the usual commercial mode now is dynamic positioning (DP), where computers are fed sensor data to enable control of various combinations of thrusters to hold the vessel in position over a spot on the bottom. To be diving certified, a DP vessel must be multiply redundant, having no possibility of a single point failure. Diving can be over-the-side or through a moon pool, a hole in the center of the ship. In its ultimate expression, a specialized purpose-built diving support vessel (DSV) with heave-compensated crane, ancillary support ROV, two moon pools with identical dive-control rooms, and two three-man bells with heave-compensated lift wire/clump weights and cursor launch system, is employed. A system such as this can keep 2 divers working on the bottom continuously for 24-hours days, diving in practically any seas. Operations such as this usually involve a second boat to deliver diving gas, groceries, water, and fuel as well as helicopter transportation for crew changes. A sixteen-man system can be split, allowing diving to two simultaneous depths. Such a system is very expensive and probably considerably beyond scientific diving needs or expectations for the foreseeable future.

300 fsw Scientific Diving Options

In this author's opinion, aside from ROV's, there are two viable options for the scientific diver wishing to personally sample at depths to 300 fsw.

Atmospheric diving suits (ADS) is the first system to consider, of which two viable commercial units exist. The Wasp, used by Oceaneering among others, and the Newt Suit or Hard Suit, courtesy of Phil Nuytten from Canada, used by Stolt and other companies as well as the USN as part of their submarine rescue program. Both are excellent units. The main advantage is long-duration dives with virtually no decompression requirement in a shirt-sleeve environment. Other advantages include the need for a smaller launch platform, smaller footprint, and reduced crew size. Any science operation would probably require at least one trained operator and one technician. Two units are always employed, one serving as a rescue diver. They are tethered, increasing the safety margin, and the technology has progressed to the point where thrusters give extensive mobility. Sample collection would not involve heavy hand work, negating one of these units' greatest limitations, limited strength and dexterity of the hand "claw". The units are relatively high maintenance but have an excellent safety record. Training would be involved, provided by the vendor if units were purchased. Extensive experience can be easily gained in a tank or pier side without the expense of a vessel. This option should be seriously explored by the scientific community.

The second 300 fsw scientific diving option is surface-supplied mixed gas diving. In it's elemental form, this diving mode involves a control manifold (gas rack), helium unscrambler radios, two dive helmets with diving hoses, oxygen analyzer, two 5120 air diving compressors, a double-lock deck decompression chamber, an open bottom bell and launch system (davit or A-frame), dive ladder, supplies of oxygen, 50/50 nitrox, high-pressure air, and pre-mix HeO_2 Divers can dive to moderate depths in temperate water in wet suits. For deeper diving or diving in colder waters, hot water suits and a hot water machine are necessary. This package could easily fit on a 130-foot supply boat if there was a location to tie up to. Otherwise, a four-point anchor boat is required for diver security. Diving on a single hook is considered unacceptable. Crew size could be as small as a Diving Supervisor, two divers, two tenders and a rack operator. Depending on training and experience, if the scientists were willing to work on deck, then perhaps four scientific divers backed up by a commercial Dive Supervisor and commercial rack operator could safely fill the bill for a minimal operation. As experience and confidence is gained, the need for professionals would decrease.

Considerations

Depending on the table employed, a minimum of 18 to 24 hours must elapse between dives. Multi-day, multi-dive missions tend to build up a high CPTD load for the divers, resulting in pulmonary decrement. Although this is temporary and recovery completes in a few days, it can increase the risk of DCS and result in decreased diver efficiency on the bottom. For practical applications, operational consideration must be given towards maximizing productivity by balancing vessel costs with time required on bottom, involving increased equipment, and larger crew size. A second chamber is usually employed so another diver can dive while the first is finishing decompression, or therapy if required, so that operations will not stop. If sufficient deck personnel are employed, one diver can be decompressing in the water while another begins a dive. The times must be carefully controlled so that a chamber is always available for all divers, including emergency considerations. This may mean a third chamber. Every additional chamber requires a 5120 air compressor and oxygen bank, with resulting increased deck equipment footprint. The dive mission and budget will determine the equipment/vessel/crew mix.

It might be useful to consider a maximum exposure to 300 fsw on the Alpha table to maximum allowed duration (operational planning limit) of 30 minutes. Bottom time is from leaving surface to leaving bottom. Allowing 4 minutes for descent to bottom, and a 2-minute “leave bottom early” safety cushion (always done in the commercial world) this result in 24 minutes of useful bottom time for the scientist. The decompression schedule requires a total of 95.6 minutes in the water at various depths breathing gas to 170 fsw, air to 90 fsw, and 50/50 nitrox to the surface. On surface, the diver then has one and a half minutes to get up the ladder or off the stage (open bottom bell), across the deck, and into the chamber. He must be recompressed to 50 ft in 30 seconds and go on oxygen within 3 minutes. He will then spend a total of 223 minutes in the chamber breathing oxygen in 20 minute periods with 5 minute air breaks. This is a total dive time of 379 minutes (6 hours, 19 minutes) from leaving water surface to reaching surface after completing deck chamber decompression for 24 productive minutes on the bottom. The scientist can write a report or read a book in the chamber, but little else.

This was the worst-case scenario. Shallower dives require less decompression, but chamber time is a price commercial divers pay for doing their work, and highlights the need for saturation diving for tasks requiring extended bottom times. These lengthy decompression times could be reduced by a technique called “repeting-up” used commercially for air diving. Unfortunately, no commercial multi-depth gas diving tables exist or are in use by any company. However, the technology exists to develop such tables. There is little need for them in the commercial arena, or they would have been produced long ago. The IFEM models, Gernhardt/Lambertsen/Miller, such as were used for the highly successful Next Generation Air Tables this author participated in at SubSea, could successfully be used to develop multi-depth HeO_2 tables, but testing of new tables is problematical and there are many obstacles to overcome, not the least of which is funding.

Training

The issue of training must be addressed. Scientific divers are undoubtedly very experienced scuba divers. Diving with surface-supplied equipment is not a great leap forward as far as the in-water component. Dive helmet familiarization and training is necessary as well as experience with hose control. Diving with a hot water suit is effortless. If the suit is well compressed (used), no weight belt is necessary, nor is a buoyancy compensator. Commercial divers normally do not use a dive computer or depth gauge either. Some use a compass, needed to determine which way to direct the crane, etc. The diver wears a bail-out bottle. The scientific diver will appreciate the freedom from equipment encumbrances that surface-supplied diving entails, once he gets used to the helmet and dragging a hose around. Topside controls the dive, depth, table, task, and time. The dive is aborted if communications are lost. The scientist may miss the independence he enjoys as a scuba diver. The dive supervisor's word is law, to be obeyed without question. He will have to learn standard hose commands and dive terminology. Bear in mind that in the commercial world, the new employee first attends a dive school, dedicating 6 months and perhaps $12,000-$17,000 towards commercial diver education. He will be hired as a tender. After gaining experience and proving himself, he progresses to diver tender, then after perhaps 1 ½ to 3 years or more, "breaks out" to Grade III diver. As the years and his skill progresses, he is promoted to Grade II and eventually, to Grade I. Normally, a diver must be at least a Grade II to gas dive, and this takes, in a normal market, at least 3 - 5 years. To be eligible for a saturation position will certainly take longer, as this attainment is recognized as the pinnacle of his profession.

It may be helpful to examine the Association of Diving Contractors International (ADCI) minimum requirements for a mixed gas diver, consisting of formal education, field experience (*i.e.*, technical proficiency) and number of working dives. Formal training at an accredited dive school must equal a minimum of 625 hours in specified subjects. A minimum of 317 hours of formal training can be supplemented by a minimum of 308 documented hours of on-the-job training in specific subjects if the entry-level diver does not have the specified hours of formal training. These are the minimum standards for entry-level Tender Diver. To achieve air diving certification, the individual must have a minimum of 100 field days of air diving operations plus 30 working dives of at least 20 minutes bottom time, all performed within 24 months prior to issuance of the designation and under proper supervision documented by a log book certified by his company. To progress to mixed gas diver, the individual needs an additional 50 days of mixed-gas diving activity plus 10 working gas dives. In practice, the commercial diver usually exceeds these requirements by a healthy margin before being trusted to dive on a gas job. These are minimum requirements.

The commercial gas diver is a thoroughly competent individual, familiar with all aspects of the diving operation, including tending, equipment set up, operation and routine maintenance, chamber operation, fixing the hot water machine and even "running the rack", *i.e.*, controlling the gas console during a dive. It is in these topside considerations the scientific diver will be found lacking and needs training to be a functioning member of a dive crew, not just a diver showing up on deck for a dive. In the beginning of the program, these elements will have to be supplied by a commercial diving company, and undoubtedly on-the-job training will be a major element towards gaining eventual operational independence from commercial supervision. A formal qualifications program, perhaps a training passport with skill sets signed off while on the job, should be set up to further this process. The ADCI's Consensus standards for Commercial Diving Operations will be a useful guide and reference in this regard.

Other Important Considerations

A situation currently exists that is unprecedented in the commercial diving field. Nearly all deep diving occurs in the Gulf of Mexico and is oil patch related. The oil fields, infrastructure, platforms, and pipelines in this area have been devastated by three successive powerful hurricanes. In 2004, there was Ivan and the oil patch was still repairing damage from that storm when in 2005 Katrina and then Rita ripped their way across the Gulf. Damage was extensive and vastly under-reported by the media. Over 100 platforms were sunk and more than 1,000 damaged. Pipelines were torn up and production decimated.

This situation has resulted in a greatly increased need for divers and their equipment. Floating assets have been drawn from all over the world. Vessels are working at the time of this writing that under normal conditions would previously never have found employment, being much too large and expensive. The pool of offshore divers decreased over the past few years and is now fully employed. Rapid expansion has diluted the general level of competence. Inland divers and companies have relocated there as well as new start-ups blossoming at never before seen rates. Prices have risen sharply and everything is scarce: equipment, divers, and particularly experienced Diving Supervisors and Superintendents. This author, after leaving the field and spending 26 years in commercial diving management, now finds himself back offshore project managing a multimillion dollar job on a 454 ft dynamically positioned Canadian vessel relocated from Mexico with a crew of 96 persons. The entire saturation dive crew is Mexican, which is unprecedented. Vessels, rental diving equipment, systems, divers, welders, riggers, crane operators, cooks, vessel masters, none are to be found.

This is a situation expected to last for several years due to the extensive damage. These factors will prove difficult to overcome when the scientific community goes shopping for equipment, vessels, or a diving contractor. Assuming a diving contractor of required quality can be found, the price will be extravagant. The contractor will have liability concerns that need to be addressed. Care must be taken to ensure that no inexperienced inland companies are employed. These companies are now hired for work they are not really equipped to perform. Having spent last fall as an Oil Company representative Inspector working with just such an inland company, personal experience saw employees called divers that by Gulf standards were barely competent tenders. The 130 ft supply vessel we were diving from normally costs $3500 per day at a premium day rate. When it blew an engine and we had to hire a similar vessel of the same size, the price was $4500 per day, and that only a month after the storms. Now one would be hard pressed to pay less than $5500. Similar increases are found across the board. This situation, while temporary, will exist for an extended period of time and must be considered by the scientific deep diving program manager.

Conclusion

In conclusion, this author believes that two viable options should be explored to develop a useful 300 fsw scientific diving capability. One is the Atmospheric Diving System (ADS), which is initially equipment expensive. It is doubtful a contractor could be found that would initially allow use of his equipment rented by scientists, even under his crew's hired supervision. By the purchase of two of these units, with assistance from the vendor and perhaps a contractor, training could progress rapidly and independent capability generated in a reasonable time. Once a track record is produced, it may be easier to find commercial contractors willing to let scientists dive their equipment as operations expand.

The second viable option is surface-supplied mixed gas diving, at first possibly by scientific divers backed up with a commercial contractor's crew and equipment. Training for the scientific diver to use surface-supplied diving gear would be relatively limited and soon achievable from several possible sources. Full program independent capability will take longer in order for the scientist to function as a full topside crew member using his own organization's dive system. Such equipment is easier purchased with long lead times at present than rented as a system from the contractor. Qualified commercial contractors willing to place a scientist on the bottom using his crew and equipment may be difficult to find in this current premium market, and liability concerns would have to be addressed.

It may be easier to develop the desired capability by hiring a qualified independent consultant(s) from the commercial world and purchasing a full diving equipment system. Current prices from Diver's Supply in New Orleans for a full system would run less than $200,000. A detailed price breakdown is provided as an attachment to this paper. Vessel platforms may exist "in house" and could be more easily contracted than the other option of using a commercial contractor. A crew of commercial divers and a supervisor could be independently hired to supervise and run the deck operations while training the scientific divers. Training programs and operational procedures manuals could be developed with such independently contracted assistance. This way the entire operation is "in house", under full control, freed from outside restrictions such as regulatory bodies and trade organizations, and can proceed as funding and personnel become available.

Attachment A. System Equipment Prices.

Vendor quote 02.22.06:
Diver's Supply
2396 Bell Chasse Hwy, P. O. Box 1663
Gretna, LA 70054
504-392-2800 Ph, 504-392-3920 Fax

Product: Gas-Diving Package for 2 Divers

Qty	Item Description	Cost ($)
2	5120 Quincy Compressor with 1250 filtration	49,500
2	Decompression Chamber, 54", double-lock, plumbed	59,990
2	Mattress, Fire resistant foam	378
6	Bib Masks	5,730
2	Chamber Radio	770
2	Oxygen Regulator	438
3	600' 4 member umbilical, color coded, tested and certified	5,607
6	Deck Whips, 50', ½" hose with #10 JIC fittings	720
4	HP (5000psi) deck whips	1,040
1	Gas Rack 1B (2lp, 4hp, 3 pneumo gauges)	7,495
2	Radio, Helium unscrambler	5,200
2	Kirby Morgan Helmets	10,000
2	Hot Water units	20,000
3	Hot Water Suits	4,200

1	Open Bottom Bell (Class II)	9000
2	Oxygen Analyzers	800
1	A-Frame launch system	25,000

*Stand-by air supply not included. (could be provided by a HP air bank)

Approx. Total $196,000

Options:	Cost ($)
Torch and 600’ lead w/ hose	3,305
Ground Lead 600’	1,778
Knife switch	202
Single Diver Radio	479
Breathing Air Regulator (CGA-346)	219
80ft^3 Scuba Bottle	140