Deep Diving Regulators

Important information for deep technical divers

Confucius once said *"It's a bad worker that blames his tools".* Although it was probably the tool companies law firm that really invented the phrase!

Confucius never scuba dived much, if he did, he would know that the tools you use underwater can affect both comfort and safety. Whilst the following text is aimed at deeper divers, it is equally valid for any adventurous diver, whether cold water dives in a lake, or drift diving in tidal areas. Over the last 10 years I have used just about every brand of regulator on deeper and deeper dives. Just about every dive has encountered equipment problems that have needed finely honed survival skills to overcome. I have often commented to manufacturers the type of problems, but nothing ever changes. Recently I contacted Stephen Burton of ScubaEngineer.com in South East Asia, Stephen listened as I explained the problems I have endured on deep dives and analysed each regulators design weaknesses with detailed engineering explanations.

Divers need to look past glossy adverts and dubious CE markings, to identify products that employ sound engineering instead of features that are seldom benefits. Most Scuba regulator designs are the result of a battle, on one side a desire to offer adequate performance coupled with a go faster stripe, on the other, the costs involved in manufacture. Although metal is the ideal material for most bits of breathing equipment, it is truly amazing to see how manufacturers like to shave down the metal in favour of cheaper plastic, after all jaw fatigue really is the number one danger underwater!

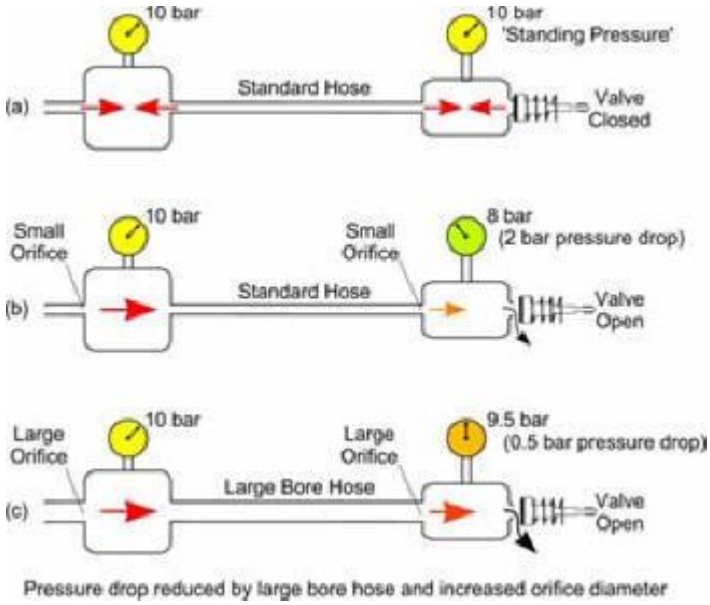
There are many points to consider when purchasing a diving regulator, the ones I am about to explain, don't often make the magazines equipment review criteria. If you are swimming at 5metres in the Caribbean and plan to do that forever, then it is safe enough to believe all the marketing hype. However if cold water, a little depth combined with some air sharing, maybe even future training are on the horizon, then the following information could prove useful.

Regulators should be made of metal. Most first stages are made of brass that has a light chrome coating, however, virtually all second stages are injection molded plastic. Plastic does have a couple of benefits, firstly its light weight making it ideal for travelling by airplane. Secondly its cheap, both price and quality. Metal second stages are far more likely to resist free flow due to thermal concerns. Metal second stages are far more resilient, lasting many more years, and servicing cycles. Another minor benefit to metal second stages is they attract condensation, this can offer a moister breath, especially useful with super dry nitrox. Plastic second stages have a reputation for being lighter in the mouth, but this is more the result of hose angle from the first stage or simply the position of the tank relative to the jaw.

First stages can be made of brass, monel, titanium and its alloys, or aluminium. 99% of regulators are constructed of brass, with 1% or less made of titanium. Titanium regulators are very light, very tough, very expensive. Low weight can be useful if you travel with heavy luggage. Titanium regulators cannot be used with enriched air. Finally, aluminium in any form is best avoided within breathing regulators as anyone who has witnessed them dissolving in sea water due to galvanic action will confirm.

Any engineer familiar with high pressure gas delivery will advise keeping the connecting hoses between stages as big "internally" as possible. Most high performance regulators use ½ inch diameter fittings on the primary hose. Typical (low) performance equipment uses 3/8 inch hose fittings, this smaller size has the negative effect of causing intermediate pressure drop, which makes the regulator lose smoothness or stutter and dramatically increases breathing resistance, causing carbon dioxide build up with the ensuing head aches or even blackout. The divers primary (½ inch port) regulator should be donated to the stressed out diver, to keep the air sharing process as comfortable and smooth as possible

Hose Diameter - Intermediate Pressure Drop



Pressure drop reduced by large bore hose and increased orifice diameter

Environmental seals are next on the agenda. Do they help prevent free flow? Who knows...? Free flow can be caused by various situations. The Environmental seal simply prevents water from entering the first stage close to the working parts. The reasoning behind sealing the first stage is, that by keeping the cold water away from the HP seat area, this may minimise freezing. I think any novice diver knows that the air leaving the first stage gets very cold, more likely is this air is colder than the surrounding water temperature. The coldness is due to reverse adiabatic compression (Joule-Thompson effect). To see for your self, open a full tank valve and notice that the tank valve quickly covers with ice as the air escapes and expands.

Environmental Seals are popular, mainly as they often associated with high performance and high quality equipment, this is mainly a marketing device to justify a higher price tag. Environmental seals keep water from circulating within the first stage, and this actually lowers the first stage temperature, thereby encouraging icing and possible free flow. As technical divers dive deeper and deeper it is important to know another highly undesirable feature of some environmental sealed first stages. Intermediate pressure amplification, or I.P boost.

Looking through promotional literature, it is easy to see manufacturers that claim their regulator actually breath easier as you dive deeper. This may have a limited benefit for divers who breath very heavily and intend diving to recreational depths. These regulators offer a lower work of breathing as you get deeper and deeper, if you are breathing regular compressed air and diving to the limits of air diving, then you may notice the regulator getting easier and easier to breath. However, this breathing assist feature will become a full free flow beyond a certain depth. I have dived using environmentally sealed regulators on hundreds of deep dives, the free flows have affected, in some instances ALL of my 5 or 6 regulators! This feature is not beneficial to technical divers going to Trimix depths, therefore It's a little surprising to see manufacturers marketing this system to deep divers. These regulators give

perfectly satisfactory performance for shallow divers. This is purely a concern for deeper divers, and for very deep dives can have disastrous outcomes.

The Environmental seal stops water from entering the first stage. If water (or its hydrostatic effects) does not manage to reach the main diaphragm, the regulator looses ambient pressure compensation. An un-compensated regulator becomes harder and harder to breath as depth increases. Manufacturers used to add a liquid (silicone oil or even alcohol) between the environmental seal and the diaphragm but this was messy and makes the first stage incompatible with enriched air. Without the oil, another means of thrust transfer must be added.

Certain manufacturers simply transfer thrust with a plastic T piece. It's the shape of the T piece assembly with its typical mushroom shape that causes the undesirable increased intermediate pressure. The process behind the design uses the Thumb tack principle...a wide surface area providing the pushing power to a smaller end. This big to small change in surface area will give an increase in pressure that very effectively causes the pin to punch through hard surfaces. In this case the larger top of the T piece, compared to the smaller diameter of the spring carrier causes a gradual increase in intermediate pressure over ambient, resulting at some depth in unstoppable free flow. If free flow arrestors are in use, the hose itself will blow! Many divers will have noticed free flow problems with Auto Airs and Air 2's and the like, when used with environmentally sealed first stages. The problem always worsens with depth...ideal.

Intermediate Pressure Boost Chart

For Environmentally sealed First Stages

Depth(msw)	Amb Pres.	Load Tx (+)Thrust(Kg)	I.P.Boost (bars-abs)	I.P.Pressure(rel)
0	1	0.00	0.00	9.50
10	2	5.65	1.20	9.70
20	3	11.31	2.40	9.90
30	4	16.96	3.60	10.10
40	5	22.62	4.80	10.30
50	6	28.27	6.00	10.50
60	7	33.92	7.20	10.70
70	8	39.58	8.40	10.90
80	9	45.23	9.60	11.10
90	10	50.88	10.80	11.30
100	11	56.54	12.00	11.50
110	12	62.19	13.20	11.70
120	13	67.85	14.40	11.90
130	14	73.50	15.60	12.10
140	15	79.15	16.80	12.30
150	16	84.81	18.00	12.50

160	17	90.46	19.20	12.70
170	18	96.11	20.40	12.90
180	19	101.77	21.60	13.10
190	20	107.42	22.80	13.30
200	21	113.08	24.00	13.50
210	22	118.73	25.20	13.70
220	23	124.38	26.40	13.90
230	24	130.04	27.60	14.10
240	25	135.69	28.80	14.30
250	26	141.35	30.00	14.50
260	27	147.00	31.20	14.70
270	28	152.65	32.40	14.90
280	29	158.31	33.60	15.10
290	30	163.96	34.80	15.30
300	31	169.61	36.00	15.50

From the I.P Boost row, you will see the current hose pressure at the corresponding depth. Many balanced second stages have a factory set yield pressure resulting in free flow between 80metres and 120 metres.

Divers must not use environmentally sealed first stages for extreme deep dives

I'm not being pedantic by explaining these regulator problems; I'm just saddened by the ever increasing technical diver accident numbers. Some of these accidents may have been prevented by better understanding of the equipment. I have been lucky to survive many underwater equipment related calamities; the equipment I use now has been chosen to meet very sound engineering principles, not simply a marketing budget.

Finally, I should talk about whether the regulator should have a "down stream" second stage valve system (99% do) or an "up stream" design. The benefits of the down stream are simple reliability. Servo assisted -Up Stream second stages have an extremely low work of breathing,

but need lots of engineering know how to achieve this. Lots of engineering may work well in a less life continuing setting. When you are underwater, simplicity is the key to survival. Many deep technical divers in the past have found there "up stream" regulator free flowing because the scuba tank pressure became too low to keep the system operating properly! Imagine...you are ascending up from a deep dive with dwindling gas supplies, maybe you are air sharing...the last thing you need is a free flow on top of everything else. Traditional down stream second stages will continue to work at far lower tank pressures than up Stream or servo assisted regulators, this is vital.

When deciding on which diving regulators to purchase, consider the future and were it may lead you. Regulator designs differ from model to model, but some clear winners are easily identified with a few hours of homework. The long and sometimes painful road I have travelled through thousands of deep dives led me to a new regulator model just last year, The Mares MR22 first stage and Abyss second stages are ideal dance partners for a tango with the deep! On the last dive to 313m the combination performed totally reliably and predictably.

Special thanks to Stephen Burton MIEE, director of SCUBAENGINEER.COM. The hours of exchanges that identified the underlying engineering designs that Stephen generously supplied were invaluable for providing a lucid and credible article.

Dive Safe, Dive Educated...

Diagrams courtesy of Scubaengineer.com and A.S.S.E.T. U.K

Mark Ellyatt