Understanding CO_2 & DIVING

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The main intension of this article is to explain how CO2 can affect divers that are using Diving Helmets and Full-Face Masks, and understand what can be done to keep CO2 levels low. This article primarily pertains to commercial/ professional divers, however this will also apply to recreational divers using open, and closed-circuit SCUBA, especially if full face masks are used.

CO_2 Production

With most healthy people the amount of CO2 produced during the respiratory process is fairly close to the amount of oxygen metabolized. The higher the breathing rate, the greater the oxygen consumed, and CO2 produced. In addition to metabolism, CO2 production is also slightly influenced by individuals' fitness and diet. The normal accepted ratio for oxygen consumption and CO2 production is for each liter of oxygen consumed, 0.9 liters of CO2 is produced. With most, the ratio is probably more like 0.75-0.85 liters of CO2 produced for every liter of oxygen consumed. Persons having a diet high in animal protein will produce slightly more CO2, than those on a plant-based diet. Oxygen consumption is based on the respiratory rate.

Respiratory Rate

Physiologist as well as other professionals specializing in respiratory studies have come up with breathing rates, properly known as respiratory minute volume (RMV), RMV is simply the amount of air ventilated through the lungs in a one minute period, basically it is the size of the breath in liters, times the number pf breaths per minute. For diving, the U.S. Navy as well as NATO, and EU CE, uses a number of RMV's to evaluate diving helmets, face masks, open circuit SCUBA, and Rebreathers. The actual blood level CO2 can be significantly affected by the breathing apparatus used, so the key for users is understanding how to use the equipment properly, in a way that will help to keep CO2 levels low. This article primarily focuses on RMV's established for diving equipment.

Re-Inspired CO_2

Simply put, re-inspired CO2 is the amount of CO2 that is re-inhaled after each exhalation. Even with nothing covering the mouth or nasal area, there will always be a small amount of CO2 re-inhaled from the area in front of the mouth and face. Covering the mouth and nose in the case of using a full-face mask, or completely encasing the head when using a diving helmet, adds what is called "Dead space". Dead Space greatly increases the amount of re-inspired CO2. With helmets and full-face masks, the "Dead Space" is the physical volume inside the equipment that encompasses the oral nasal cavity and/or freely communicates with entire mask or helmet due to leakage around the oral nasal mask, poor design or sheer excessive volume. No matter what, when using helmets or full-face masks, there is always a portion of previously exhaled breath re-inhaled due to dead space. Now, think about a simple diving snorkel. When breathing from a snorkel as the user reaches the end of an exhalation the tube is filled with a mixture containing approximately, 4.0-to 4.5% % CO2. The very last portion of the exhalation through the snorkel will have the highest percent of exhaled CO2. For the European Union (EU) CE testing we assume 5% at the end of the breath (End Tidal). At the beginning of the next inhalation, the entire volume of the snorkel is re-inhaled into the lungs first, this portion of air is high in CO2 and comes in first before any fresh air makes its way in. The larger the physical volume of the snorkel the greater the amount of re-inspired CO2. With many diving full face masks if the mask is not fitted or used properly the dead space volume within the mask but outside the oral nasal mask can join with that of the oral nasal, significantly increasing the amount of re-inspired CO2.

Understanding the Effects of CO_2

Understanding the effects of CO2 on the diver is of great importance especially for divers using full-face masks, helmets, or anything that can increase CO2 in the breathing circuit. Some commercial diver training schools do not place enough importance on minimizing CO2 retention in diving apparatus and body. Unlike open circuit SCUBA, where re-inspired CO2 is minimal due to very little dead space, helmet and full-face masks can have a significant amount of dead space by design and if not fitted properly, or not keeping the breathing resistance low, can cause CO2 blood levels to reach high levels.

Understanding the Effects of CO_2 (continued)

The sneaky, and insidious effects of CO2 often go unrecognized. Symptoms range from labored breathing, shortness of breath, irritability, headache, confusion, not necessarily in any particular order. As the blood level CO2 increases the divers judgment will be impaired do to the narcotic effect of CO2 which is also compounded if the diver is diving deeper than 100 fsw on air do to nitrogen narcosis. In many cases it is not the high CO2 that does the diver in, but rather, the accident that results from poor judgment from the effects of the high CO2. Understanding the signs and symptoms of high CO2 and what to do is important, let's review of the basics below.

Symptoms of CO_2 Exposure

The symptoms of elevated CO2 will generally be more pronounced when diving, as compared to the surface due to elevated gas density and increased breathing resistance. One of the most common symptoms is loss of concentration others include those listed below and may appear in any order.

- Irritability
- Increased breathing rate
- Shortness of breath
- Narcosis
- Confusion/disorientation

More Re-inspired CO_2

As mentioned earlier about the snorkel, which is a pure example because of its smooth cylindrical shape which allows all the gas to transfer similar to liquid in a syringe, even when a small breath is taken. Now picture breathing from an irregular shape such as an oral nasal mask, full face mask, or diving helmet, the exchange of gas eddies, tumbles, and does not exchange smoothly like the snorkel. For this reason, a snorkel having the same physical volume as an irregular shaped item like an oral nasal mask will show more re-inspired CO2 due to eddying, swirling within the irregular cavities of the mask and breathing components.

Primary Factors Influencing Re-inspired CO_2

There are basically four factors that influence the amount re-inspired CO2. "Physical Dead Space Volume", "Gas Flow Path", "Breathing Resistance" and lastly proper ventilation. Proper ventilation does not apply to a breathing simulator, but does to a human. Improper ventilation primarily pertains to divers that "Skip Breath".

Dead Space

The dead space is the volume within the item being breathed through, however it can also be linked to the space within a full-face mask or helmet. With a simple SCUBA regulator or snorkel, the physical volume is very small, (less than 200 ml) and generally the potential for significant re-inspired CO2 is minimal. However, if you take the same regulator or snorkel and attach it to a full-face mask with an oral nasal that does not seal well to the face, both inhalation and exhalation gas may escape from the oral nasal mask interior to the interior space of the full face.

Gas Flow Path

The gas flow path is simply how smooth and how well the gas can move through and exchange the gas within the space. Gas flow path is important because even though the actual dead space volume may be small, if the gas swirls and eddies, the CO2 level will show a higher value.

Breathing Resistance

Breathing resistance and compliant volume are directly linked when using a full-face mask or diving helmet. The compliant volume of the system is the expansion and contraction of the physical breathable volume within the helmet or full-face mask due to the face seal or neck dam volume change. If the inhalation effort is high, the neck dam and compliant spaces will contract allowing the user to breathe this gas, which may contain trapped CO2. The volume change acts much like an accordion or bellows, this is especially true with diving helmets that have excessively large neck dam expansion and contraction compliance.

Breathing Resistance (continued)

Even full-face masks can have significant expansion and contraction of the face seal if breathing resistance is high. Keeping the helmet or mask in tune and adjusted for least amount of cracking pressure helps reduce the compliant volume exchange effect.

Improper Ventilation

Most commonly known as Improper Breathing or "Skip Breathing". For surface supply helmeted or mask divers, it is important to breathe long and deep in a comfortable manner. Never take short shallow breaths. And never skip breath as some SCUBA Divers do in an effort to conserve air. The surface supplied diver should never work at a level so high that the diver cannot carry on a simple conversation with topside. When breathing at low ventilation rates such as performing light work or during decompression, the surface supply diver should crack open the steady flow slightly and set up a very slight hiss, or set a very light free flow through the demand regulator just enough to keep a very small, almost unnoticeable flow of gas into the helmet or full face mask. This will keep the CO2 low. Recreational divers should never work at high rates! Recreational divers should try at all times to breathe normal and avoid extreme ventilation rates.

Minimizing CO_2 for the Diver

- ✓ For helmets and full-face masks, ensure the oral nasal fit is good, this means making sure the headliner of the helmet is packed so the helmet fits and keeps the face planted in the oral nasal mask, so that when the head moves the helmet moves with it. "Proper Pre-Dive Preparation."

- ✓ "Ensure", the oral nasal one-way valve, seals properly in the oral nasal mask, and the microphone is properly installed in its space. "Proper Pre-Dive Inspection."

- ✓ The Diving Supervisor must, ensure the supply pressure is adequate for the diving depth.

Minimizing CO_2 for the Diver (continued)

- ✓ The Diver should keep the demand regulator bias device (Dial-a-Breath) adjusted for lowest inhalation resistance and should readjust it after depth changes and whenever the divers physical attitude is changed.

- ✓ Breathe deep and normal, never skip a breath. When at rest or very light work rates, set up a very slight free flow to help keep the background CO2 low.

- ✓ During moderate to heavy work rates, the diver should take at least a 3 second vent every two to three minutes, by cracking open the steady flow valve a 1/8-1/4 turn. Note: You do not need to blast a lot of gas into the helmet, simply flowing light flow by opening the steady flow open 1/8 to ¼ turn for 3-5 seconds, is all it takes to completely flush out the helmet.

- ✓ During periods when the breathing rate is very low such as during decompression the diver should crack open the steady flow slightly or set up a slight hiss on the demand regulator just enough to keep a very small, almost unnoticeable flow of gas into the helmet or full-face mask.

Snorkel Full Face Masks

Over the past few years the snorkel full face mask market has exploded. These masks have become very attractive especially for people that have never snorkeled before. Those on vacation or a cruise to exotic islands, where snorkeling is good like the thought of not getting their face wet while looking at the sea life. Users beware! While these masks look very cool and simple, they can come with hidden dangers. Testing at Dive Lab has found most of the masks we have tested were extremely high in re-inspired CO2, due to large dead space as well as compliant volume. Some of these masks did not even have routing valves to prevent re-inspiration. Almost all of the masks we have tested far exceed established re-inspired CO2 limits set by the EU standards, as well as the U.S. NAVY and others.

Snorkel Full Face Masks (continued)

Unfortunately, it shows how little this industry understands about these types of products, and this may be going completely unnoticed by users because they put their faith in a cheap product that looks cool. They bought it thinking this was a "No Brainer." Dive Lab is not the Diving Police. This information is a byproduct of testing we have done, and do on regular basis while testing breathing equipment. Persons purchasing a snorkel mask must ensure it comes with a technical sheet that explains the limitations of the mask, as far as breathing rates and re-inspired CO2. The manufacturer of the Snorkel mask should provide this information. In addition, the manufacturer should provide information on recommended use.

For more information on CO2, please see our Testing Re-Inspired CO2 Article on our website at divelab.com.

The End