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Solving Cold Water Breathing Problems

by - Bev Morgan, Pete Ryan, Trent Schultz, and Mike Ward

The results of recent tests at the Dive Lab in Panama City Beach, Florida, reveal a problem that has gone relatively unnoticed and unreported in open circuit scuba diving for many years. **Bev Morgan, Pete Ryan, Trent Schultz, and Mike Ward** outlines the reasons behind the difficulties divers encounter when breathing in cold water.

The refrigeration effect of gas pressure reduction in open circuit scuba is known, but has not been the subject of published information due to the lack of investigation on the subject. The refrigeration effect has been recognized as a factor in mechanical failure of the demand regulator when scuba diving in cold water, but the exact mechanical source and effect has not been defined. Most all divers have noticed that the air/gas coming from the open circuit demand regulators is cold, but just how cold? The physiological effects and possible danger to the diver of the refrigeration of the breathing gas/air has not been investigated, to the authors' knowledge.

In commercial diving operations using Helium and Oxygen breathing mixtures (HeliOx) and umbilicals, it is common practice to use hot water systems to heat the exterior of the divers' body and the breathing gas. It is known that the breathing gas must be heated (in addition to heating the exterior of the body) for the divers' core temperature to be maintained. Heating only the exterior of the diver's body is not enough to keep the diver warm.

HeliOx transfers heat about seven times more efficiently than air or Nitrogen/Oxygen mixtures (NitrOx). Divers using HeliOx on deep dives rapidly become cold by loss of body heat through respiration. The problem is overcome by heating the diver's breathing gas (in addition to heating the exterior of the body). This is accomplished in most commercial diving operations with a flow of hot water through a shroud over the piping in which the diver's breathing gas flows. The hot water is produced at the surface and sent to the diver through a hose that is part of the umbilical.

Scuba divers are not connected to the surface and do not have this means of warming. Heating the scuba divers gas/air supply has not been done successfully. Scuba heating efforts have focused on the exterior of the body by means of passive insulation and more recently, electrical heating with batteries.

Pressure and Temperature

Since no obvious indicators point to cold inhalation gas/air being a problem to scuba divers; it appears that no studies have been done to investigate this cold breathing gas/air effect on their physical well being.

Mechanically, breathing regulators have been modified to retard freezing. While some designs do work to retard freezing, little success has been achieved in warming the gas/air temperatures to the diver.

Scuba divers store their supply of breathing gas/air in tanks that contain the compressed gas/air. Pressures of 3,000 psi (206.8 Bar) are common in the United States, with 4,000 psi (275.8 Bar) common in Europe. In some cases technical divers have used pressures of 6,000 psi (413.7 Bar) or more. The use of higher-pressure storage tanks and mixed gas by deep divers has significantly increased the potential danger and risk associated with the breathing gas/air cooling effect of pressure reduction by the first stage regulator.

A first stage regulator, usually attached to the tank valve, reduces the tank pressure to approximately 150 psi (10.3 Bar) this lower pressure is fed by means of a hose to a second stage demand regulator that is located near the divers' mouth.

The reduction in pressure by the first stage causes the compressed gas/air to greatly expand at the first stage flow orifice. The rapid expansion of gases dramatically reduces the temperature of the breathing gas. The Dive Lab has found that drops of 50 degrees F (27.8 degrees C) are common, and drops of 100 degrees F (55.6 degrees C) or more are possible when 6,000 psi (413.7 Bar) storage pressures are used.

The cooling appears to be linear and predictable. The higher the pressure at which gas is stored, the greater the temperature drop will be when the pressure is reduced to a typical low pressure of about 150 psi (10.3 Bar).

When the diver is immersed in relatively warm water of 75&186; degrees F (23.9 degrees C) and is breathing from a tank of compressed air filled at 3,000 psi, the low pressure air coming out of the first stage regulator is in the range of 25 degrees F (or minus 3.9 degrees C). That is below freezing.

Most scuba divers do not sense this cold breathing gas and are not concerned. However, even at these warm water temperatures when using air or NitrOx, divers have been unknowingly using a great deal of body heat/energy to warm the cold gas inhalations. The lower temperature of the breathing gas shortens the time that it takes for the diver to get uncomfortably ³cold² and start to shiver. In addition to diver heat loss through respiration, the cold inhalations are very dry, causing increased dehydration to the diver.

When the water temperature is 40 degrees F (4.5 degrees C), the temperature of the breathing gas is in the range of minus 10 degrees F (minus 23.3 degrees C) when the tank is full to about 3,000 psi (206.8 Bar).

When the water temperature is 32 degrees F (zero degrees C) the demand second stage regulator is being fed minus 18 degrees F (minus 28 degrees C) gas/air when the tank is full to about 3,000 psi (206.8 Bar). During testing, ice build-up on the regulators being tested was impressive. There was one-half-inch coating of ice inside and outside of the demand second stage, and the first stage was encased in a large, thick ball of ice. Needless to say, the second stage mechanically failed in less than five minutes. A first stage equipped with a cold water environmental cap mechanically failed due to being entirely encased in ice.

Effects of Cold Water Diving
At these temperatures there is an immediate danger to the diver in two ways. First, ice may cause the regulator to mechanically freeze up, threatening the diver's supply of breathing gas. Second, the cold air hitting the diver's mouth, throat, and airways presents a real danger of causing respiratory shock, which results in the diver being instantly rendered unable to breathe.

The physical mechanism of respiratory shock is not fully understood by the authors. It appears that laryngospasm occurs. The diver's airway is completely blocked by the epiglottis, sealing the trachea closed. If the airway is blocked, embolism can occur even in relative shallow water if the diver goes toward the surface. Whatever the exact physical mechanism to the diver, the result can be catastrophic. This may explain why some previous cold-water diving fatalities have happened without an apparent cause.

Panic may be the catch-all explanation, but the authors suspect that respiratory shock can be the true cause for the panic and the real cause of the problem. Certainly anyone who has observed a diver experiencing severe respiratory shock would see it as panic.

The diver, if he or she survives, may be confused and interpret the event as a sudden mechanical blockage of regulator gas/air flow, since there is little awareness in the scuba diving community of respiratory shock, let alone identifying the event.

When a diver is using Helium in the breathing mix the danger is compounded. This is due to the greater heat transfer characteristics of Helium mix at depths where this mix is used.

A technical scuba diver using Helium in the breathing gas mixture switches to this mix from a nitrogen mix during descent, usually deeper than 100 feet (30m). At these depths the water temperature can be below 40 degrees F (4.5 degrees C). The tank of Helium mix would be full. If 3,000 psi (206.8 Bar) were the tank pressure, the first two or three inspirations would be at minus 10 degrees F (minus 23.3 degrees C). Even lower temperatures of the inspired gas are found with the continued reduction in temperatures of the metal breathing regulator system caused by the refrigerator effect of the first stage regulator.

It is not known at what temperature respiratory shock occurs in divers and it undoubtedly varies from diver to diver. We believe that minus 10 degrees F (minus 23.3 degrees C) on any gas including air, but especially Helium mix, is cold enough to cause a serious danger to any diver. This means any diver in water that is below 45 degrees F (7.2 degrees C) or so, can be on the threshold of respiratory shock if their breathing source is a scuba tank of compressed gas/air.

If breathing mix is stored at 6,000 psi (413.7 Bar) the temperature of the inspired gas to a diver in 40 degrees F (4.5 degrees C) water can be around minus 60 degrees F (minus 51.1 degrees C). In cold water technical scuba diving, switching over to a tank of HeliOx that is stored at 6,000 psi (413.7 Bar), in our opinion, can be extremely dangerous.

High percentage Helium mixes in deep commercial diving operations require the incoming gas temperature at the diver to be above 100 degrees F (37 degrees C). Below that, the diver's time underwater is shortened in direct proportion to the lowering temperature of inspired gas.

The deep commercial diver that experiences interruption of gas flow in their umbilical must switch to emergency gas, which is usually an open circuit system supplied by a high pressure scuba tank. If the hot water flow is also interrupted, the diver will receive only very cold gas from the tanks. This is a very dangerous situation.

Heating the Breathing Gas

From the above information the obvious solution to the problem is to heat the breathing gas/air of any deep water or cold water scuba diver. Deep water or cold water commercial divers, as well, should heat emergency gas/air that is supplied from high-pressure tanks worn by the diver.

Power is necessary to do the work of heating. We believe that Kirby Morgan Dive Systems has a potential solution to this problem in the works and will publish the results when they are available.

Many years of scuba and commercial diving in moderately cold water have been done seemingly without problems from cold gas. Careful observation and awareness by divers can help all of us understand how cold breathing gas truly affects us.

Bev Morgan is Chairman of the Board at Kirby Morgan Dive Systems. He began designing and manufacturing diving equipment in 1950 and continues today. Along with Bob Kirby, Bev designed the Kirby Morgan Superlite Helmets and Bandmasks. He now lives in Panama City, Florida, where he is working on several new commercial helmet and mask designs.

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