CARBON MONOXIDE IN DIVING

In his book 'The Silent World' Jacques Cousteau described a cave dive where the divers' experienced unusual symptoms and were on the edge of consciousness. Investigation of the incident found that the air in the cylinders had been contaminated with carbon monoxide from a faulty compressor. This was over 50 years ago. Unfortunately, diving incidents, some fatal, are still being caused by carbon monoxide toxicity from contaminated breathing gas.

Carbon monoxide is a colourless and odourless gas that is highly toxic. Toxicity primarily results from cellular hypoxia. Carbon monoxide has a nominally 300 times greater affinity for haemoglobin than oxygen, so displaces oxygen and reduces the ability of the blood to transport oxygen around the body. The body is further starved of oxygen because, once it is bound to carbon monoxide, the haemoglobin molecule changes shape and it releases oxygen much less readily. At a cellular level there are additional toxic mechanisms, especially those affecting the circulation and the nervous system, that add to the complications and long term effects of carbon monoxide toxicity.

The level of carbon monoxide toxicity is normally expressed in terms of both the concentration of carbon monoxide, as inhaled, and the percentage of haemoglobin carrier sites that are bound with monoxide. An inhaled concentration (at atmospheric pressure) of 200 ppm (0.02 %) may result in 15-20 % of haemoglobin sites being bound; at this level, clinical symptoms such as headaches, fatigue, nausea and dizziness would start to occur. Active smokers may inhale carbon monoxide levels up to 60 ppm and have 10 % or more of their haemoglobin bound with carbon monoxide. In the US, there are a range of eight hour time weighted average occupational exposure limits for carbon monoxide; Occupational Safety and Health Administration (OSHA) specify 50 ppm, National Institute for Occupational Safety and Health (NIOSH) 35 ppm and the American Conference of Government Industrial Hygienists (ACGIH) 25 ppm.

When considering the toxic effect of gases during diving, it is the partial pressure of the gas, rather than the fraction or percentage that should be considered. An air dive to 165 fsw (6 ATA) will expose the diver to a total gas pressure 6 times that at the surface, thus breathing a carbon monoxide level of 33 ppm at 6 ATA could be considered clinically equivalent to breathing 200 ppm at atmospheric pressure (1 ATA). However, as depth increases so does the inspired partial pressure of oxygen, offering some mitigation against the affinity of carbon monoxide over oxygen to bind to haemoglobin. For air diving, it is typical to specify a maximum acceptable level of contaminants at a level of 6 to 10 times less than those acceptable at the surface.

Carbon monoxide is produced as the result of an inefficient combustion of hydrocarbons; instead of being completely converted to carbon dioxide and water, the combustion also produces carbon monoxide and other chemical species. There are primarily two mechanisms by which an unacceptable level of carbon monoxide may end up compressed into diving cylinders. Probably the best understood is carbon monoxide being drawn into a compressor inlet from an external source such as a motor vehicle exhaust or other fossil fuel combustion e.g. gas heaters. A second, more subtle method is pyrolysis (chemical decomposition by heat) and may occur when a compressor is hot, but not necessarily overheating. Pyrolysis may cause the lubricating oil in the compressor to break down releasing carbon monoxide, or other plastic/organic compounds in the system to decompose creating toxic chemical species. The risk of carbon monoxide poisoning as a result of either of these mechanisms may be reduced by correct compressor operation and maintenance. Positioning of the inlet away from and upstream of exhaust fumes, use and periodic replacement of the correct lubricating oil, ensuring compressors are adequately cooled and including a carbon monoxide catalyst (such as hopcalite) in the filter system.

The quality of compressed air from a compressor or supply bank may be checked by portable test apparatus (such as colorimetric gas detector tubes) or by taking a sample for detailed laboratory analysis. Samples for analysis are typically taken every three or six month, or with portable compressors each time they have been moved to a new location. Whilst this is a very useful procedure for monitoring routine maintenance and filter performance, it would not identify an acute event between samples, e.g. a combustion exhaust, unknown to the compressor operator, being moved close to the inlet or a component overheating and producing carbon monoxide by pyrolysis.

Analysis of diving incidents has shown that high levels of carbon monoxide may be found in the diving cylinders, even if the air from the compressor was analysed at the recommended test intervals. Commercial surface-supplied diving recognises the risks of a sudden change in supply gas to the diver, and employs on-line analysis of the divers breathing gas. It is reasonable to apply a parallel logic to all diving compressor and breathing gas supplies, and to continuously check the level of oxygen and major toxic components, in the air being used to fill diving cylinders. We can hope that adopting this approach would be a further step in the ongoing process of increasing dive safety.

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