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# SCUBA Tank Corrosion As a Cause of Death

Compressed air for breathing purposes is used by firemen and by professional or sport divers. A sport diver, using self-contained underwater breathing apparatus (SCUBA), is probably the most susceptible to potential dangers from impure air due to the lack of trained supervision or control and the great degree of individual freedom enjoyed by sport divers. It is likely that members of this group, often poorly trained and ignorant of the need for care of equipment, would be most susceptible to the dangers which result from compressed air gas cylinder corrosion.

Because gas cylinders are frequently subjected to rough handling or a corrosive environment, there is potential danger from corrosion. The Interstate Commerce Commission regulations of the Department of Transportation require that gas cylinders shipped in interstate commerce or utilized for commercial purposes be subjected to a hydrostatic test every five years. Because of this precedent many privately owned SCUBA cylinders are similarly tested in accordance with federal guidelines. A recent study [*1*] indicates that visual inspection of tank interiors will frequently reveal corrosion products, although the tank may be sufficiently strong to withstand a hydrostatic test pressure of 3750 pounds per square inch. Moisture, a precursor to corrosion, may remain within the gas cylinder as a result of the hydrostatic test, may be introduced as a result of improperly filtered air, and may enter if air is depleted and a single hose regulator has the purge button inadvertently opened with the mouthpiece under water. A saltwater swimmer could easily contaminate his tank in this way [*1*]. In the study mentioned above, a dangerous corrosion occurred in as little as three months, resulting in weakened tanks. Interior corrosion may occur in a uniform manner or there may be pitting corrosion or stress corrosion cracking. The iron content within the steel may result in various oxides including red-brown rust, $2Fe_2O_3 \cdot (H_2O)_2$. As oxygen becomes depleted green hydrated magnetite, $2Fe_3O_4 \cdot H_2O$, may be formed or even magnetite, $Fe_3O_4$. Although Peyser et al [*1*] have discussed in intimate detail mechanisms and types of corrosion, no mention is made of the potential harmful effects of inhalation of air from such a tank.

If air depleted in oxygen is breathed, serious hypoxic symptoms may occur. When oxygen drops from the normal 20% to 10%, dizziness may ensue and, at 7%, may lead to stupor. Below 5% is incompatible with life [*2*]. Symptoms and effects may be

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insidious because the victim exhales carbon dioxide in a normal manner and thus experiences no uncomfortable symptoms attributable to carbon dioxide stimulation of respiration. Without warning he may experience only disorientation followed by unconsciousness. This may be only a matter of minutes or seconds, depending upon the oxygen deficiency of the air being breathed. The following case study amply illustrates this dangerous situation.

**Case Study**

This 46-year-old white male donned his 71-ft³ SCUBA tank equipped with a K valve and a single hose regulator. He dove into a 12-ft-deep fresh water canal to recover a lost motor. A witness could not see the victim due to turbidity of the water, but estimated that the bubbles ceased in approximately 5 minutes. However, this time cannot be established with certainty. The victim was a good swimmer, was familiar with SCUBA, was sober, and had no history or evidence of natural disease. At autopsy the only findings were those of drowning, including pronounced pulmonary edema, water in the sphenoid sinus, and vascular congestion of the petrous bones of the skull.

The tank was a 71-ft³ steel cylinder which was estimated to be approximately three decades old, according to what appeared to be a month and year mark "6 41." The last hydrostatic test was apparently four years previously. The tank contained a little less than 200 psi of air pressure. The regulator filter was noted to be soiled with a black, scale-like material. The initial purge was sluggish but was adequate when the regulator was placed upon a tank containing 2000 psi of air pressure. It must be presumed that the diver would have noticed a severely clogged filter, for he was under no compulsion to continue this dive in relatively shallow water. Analysis of the residual air with a Beckman D-2 oxygen analyzer revealed an oxygen concentration between 2 and 3%, instead of the normal 20%.

The tank was sawed open and the interior was noted to be markedly corroded with black scale and some orange-red spots of lighter colored rust, as shown in Figs. 1 and 2. Subsequent investigation revealed that the tank had been filled at a commercial dive shop some three months prior to the fatal dive. It had been partially used at that time and then stored at home.

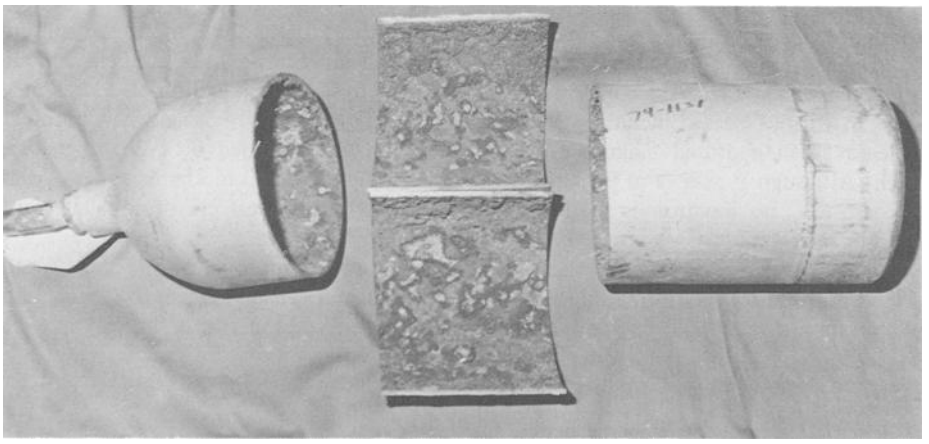

FIG. 1—*Lack of external corrosion as compared with the interior of the tank.*

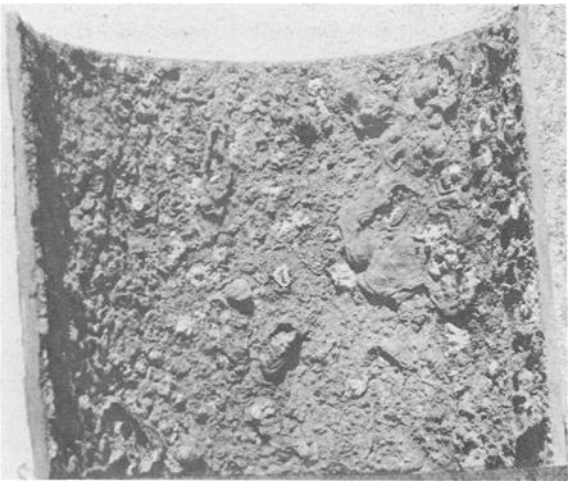

FIG. 2—*Massive internal accumulation of corrosion products.*

## Discussion

Three hundred and ninety-one known SCUBA fatalities have occurred in the United States during the years 1946 to 1970 inclusive [*3*]. No specific report of an oxygen depletion mishap proven by analysis of the air is to be found in the medical literature or published reports, although such a possibility has been suggested [*4*]. This does not necessarily indicate the lack of occurrence of such events. In only 6 cases out of 110 during 1970 was any chemical test made on gas involved in a fatality [*3,5*]. Thus, it has not been possible in most reported cases to judge how many air purity failures result in diving casualties. In one newspaper report a 26-year-old lifeguard was found on the bottom of a swimming pool [*6*]. There were findings of drowning at autopsy. His tank was a converted fire extinguisher and was half full of rusty water when emptied. Although no analysis was performed, the circumstantial evidence of an oxygen depletion mishap is quite strong. In another incident [*5*] the victim died after using a very rusty tank. A friend of the victim took three breaths from the almost empty tank and reportedly became ill. Unfortunately the tank was empty when it was submitted to a laboratory and no gas analysis could be performed. Yet another reported incident involves an analogous circumstance where a diver breathed air from a pocket inside a sunken barge. He succumbed and it was assumed on the basis of circumstance that corrosion activity had exhausted the oxygen in the air pocket [*3*]. There seems little doubt that determination of oxygen content of residual air in compressed air breathing tanks is a necessity in the investigation of a diving mishap.

The investigation of a SCUBA mishap should include an intensive determination of all circumstances and background information pertaining to the diver and the event. A complete autopsy should be performed with tests for drugs, alcohol, and carbon monoxide. The equipment should be carefully examined for any evidence of mechanical failure and residual air should be analyzed for carbon monoxide and oxygen content. An oxygen analyzer may be borrowed from the anesthesiology department of a hospital. The tank should be carefully inspected, inside and out, to determine if it has been properly maintained, has been regularly given hydrostatic tests, and is free of any evidence of

corrosion. Even if the gas analysis reveals no hazard, the interior of the tank should be visually inspected. In the event that the tank is corroded it should not be returned to the owner for continued use.

The prevention of such mishaps must depend upon a program of acquisition of proper equipment and regular inspections, not just the infrequent hydrostatic pressure tests. Corrosion resistant tanks may be preferred.

Divers who have their tanks filled prior to storage are less likely to experience a problem with oxygen depletion than those who store partially filled tanks. The amount of corrosion product formation required to lower the oxygen concentration a given amount is less for a partially filled tank than for a fully charged one. Approximately 8.4 lb of ferrous hydroxide must be produced in order to lower the oxygen concentration from 20 to 3% in a fully charged SCUBA cylinder (approximately 5.35 lb of air). On the other hand, only 0.84 lb of ferrous hydroxide must be produced in a tank stored at 10% of its capacity (approximately 250 psi or 0.53 lb of air) [7]. Thus, a diver who uses the remaining air in a SCUBA tank which has been stored partially filled is more likely to experience corrosion-related oxygen depletion than a diver who stores the tank fully charged.

Tanks should be subject to visual inspection at least every twelve months. Even a corrosion resistant tank may acquire oil, water, or dirt contamination which could constitute a hazard or cause a malfunction. If the tank is found to be dirty it should be cleaned before refilling. If it is seen to be badly corroded it should be removed from service. The hydrostatic test regulations should be amended to prevent approval of a pressure-safe, yet corroded, tank. A tank that has been allowed to become completely empty must be visually inspected regardless of its last visual inspection date. This is because water may have been allowed to inadvertently enter the tank due to the lack of pressure within. Tanks held in reserve for use by firemen or other professional or commercial individuals must be subject to a regular routine of exhaustion of the air, visual inspection, and immediate refilling. In steel tanks it is preferable to keep the tanks upright in the event that some moisture has collected. Corrosion under these circumstances would tend to be confined to the bottom, a smaller and thicker area.

These recommendations are supported by the following one-year experience of one well-run local dive shop:

| | |
|---|---|
| Hydrostatic tests with visual inspection, tank clean | 231 |
| Hydrostatic tests with visual inspection, needed cleaning | 114 |
| Visual inspection only, tank clean | 362 |
| Visual inspection only, needed cleaning | 71 |
| Total number of visual inspections | 778 |
| Total number of cleanings | 185 |

It may be seen that almost one-quarter of tanks visually inspected had sufficient dirt and scale to necessitate cleaning. There is no uniformity in the degree to which dive shops inspect tanks. Recently the authors submitted an empty tank with no inspection sticker to seven dive shops. Only three of the seven required a visual inspection because the tank was empty.

Although there may be no governmental regulations in many areas, dive shop

operators may be subject to civil liability in the event that it can be shown that the user of the tank was damaged as the result of the negligent filling of an unsafe tank.

## Summary

Corrosion of compressed air breathing tanks may result in dangerous oxygen depletion. In every SCUBA mishap the residual air should have, as one of the tests, a measurement of oxygen content. The tank should also have a visual inspection. All compressed air breathing tanks should have a routine visual inspection on a regular basis, even if the tank is made or lined with corrosion resistant material.

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## Addendum

Since preparation of this manuscript, an analogous case has occurred. An adult experienced in SCUBA use donned borrowed equipment to recover some metal lost in about 15 or 20 ft of water. He lost consciousness before submerging. He was immediately rescued and was areflexic. After resuscitation he underwent a stormy course of irrational behavior but recovered consciousness in about four hours. The tank contained no oxygen but had a charge of helium at a pressure of 1950 psi. The circumstances behind this occurrence are still under investigation.

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