BACKGROUND

Currently, the CO_2 scrubber in a rebreather is not monitored during dives.
Stated endurance times rely on worst-case testing at assumed diver workloads. Therefore, the full capacity of the CO_2 absorber is unlikely to be used. If the scrubber could be monitored, dives could be safely extended or shortened as dictated by actual events.

A CO_2 sensor might seem to be a good solution for monitoring the scrubber. However, sensors are not yet available for the harsh diving environment and, typically, there is no CO_2 to sense until 60 to 80% of the absorbent is spent (Figure 1);

> A CO_2 sensor does not allow for any planning and can only provide a warning.

A scrubber gauge is the missing component for monitoring rebreathers.

Since the absorption of CO_2 is an exothermic reaction this project takes advantage of a method that uses temperature changes inside the scrubber to provide a readout like that of a fuel gauge (Warkander, 2003).

METHODS

A large number of temperature probes (Thermometrics MA100BF-103-A, Edison, NJ) were placed inside the scrubber of a model of a rebreather. Temperatures were recorded (Figure 2) during normal endurance runs at the full range of water temperatures, depths and levels of exercise (with normo-, hypo- and hypercapnia) and mission-like runs (including multiple dives and multilevel dives). Three different CO_2 absorbents (High Performance Sodasorb 4-8 mesh, W.R. Grace, Chicago, IL; Sofnolime 4-8 mesh NI L grade and 812 mesh NI D grade, O.C. Lugo CO, New City, NY) were used.

The temperature increases inside the absorbent were calculated and normalized to the highest increase (Warkander, 2003). This normalized ratio was plotted against time for all runs and was used to decide when a scrubber gauge should read empty.

After the temperature sites were chosen, a prototype was to be built and its performance verified in both unmanned runs and manned dives.

RESULTS

About 1,000 scrubber hours were spent under pressure. The endurance times varied drastically with water temperature and simulated diver workload (minute ventilations were 22.5, 40 and 62.5 L/min, CO_2 injection rate was either 3.4, 4 or 4.7% of the minute ventilation).

Sites for temperature probes that are suitable for gauge readings were found. They allow for a mechanically robust system.

A proof-of-concept unit gauge (Figure 3) was built and its performance was confirmed in an additional 40 unmanned dives. Sample readouts are illustrated in Figure 4.

Dives with Navy divers demonstrated the performance of the proof-of-concept gauge.

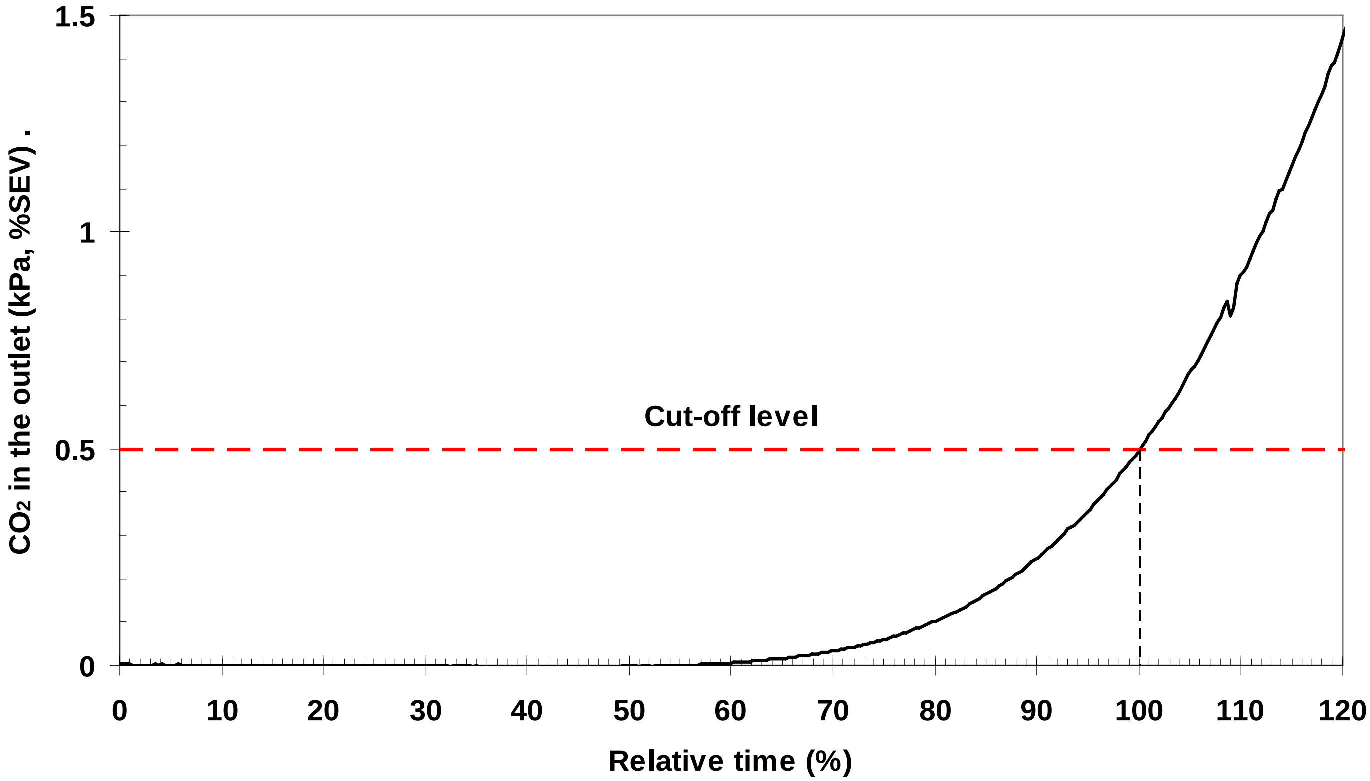

Figure 1. Typical pattern of inspired CO_2 from a scrubber throughout a dive.

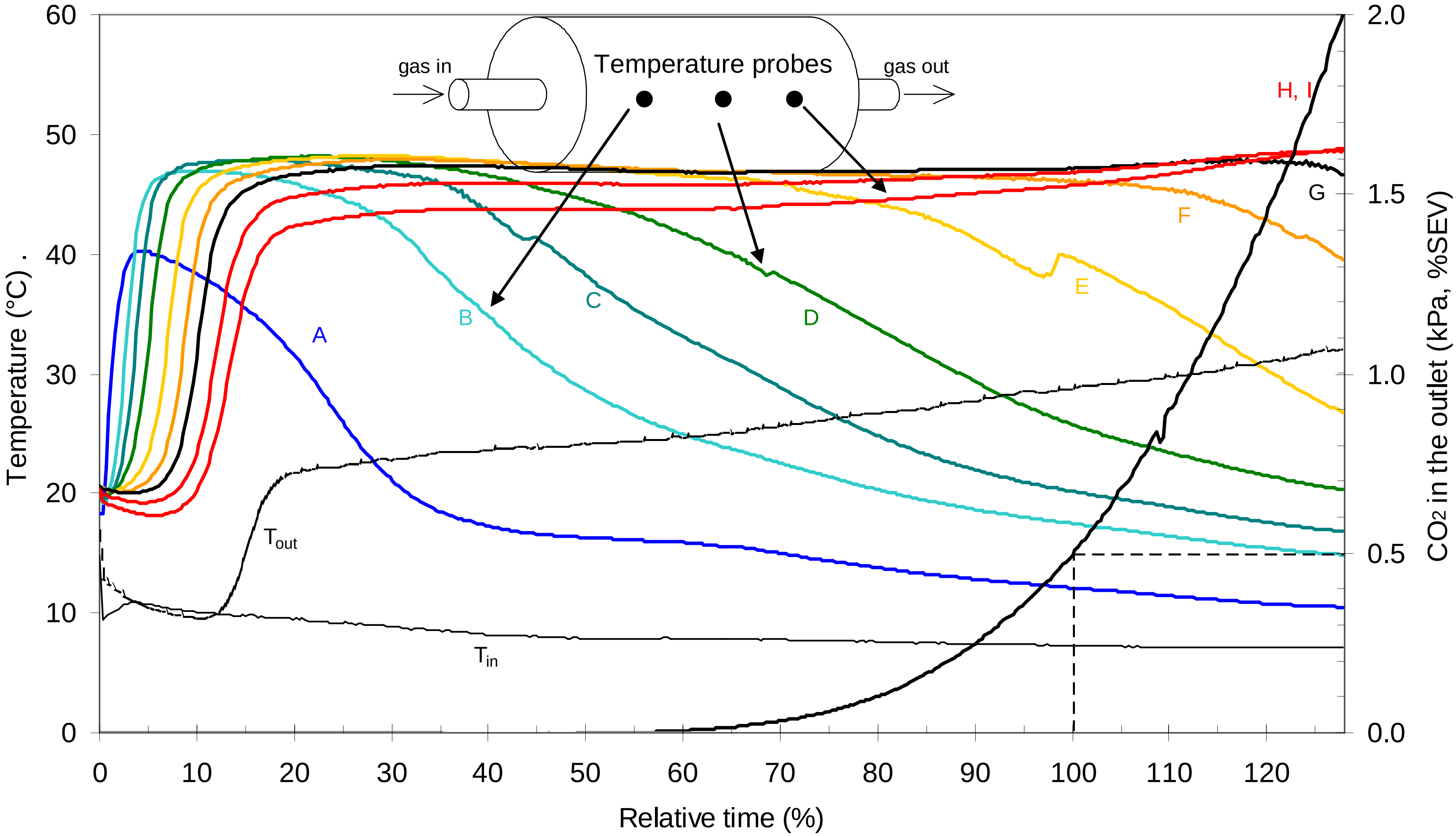

Figure 2. Typical temperature changes during a dive. A relative time of 100% defined as the time when the outlet CO_2 was 0.5 kPa.

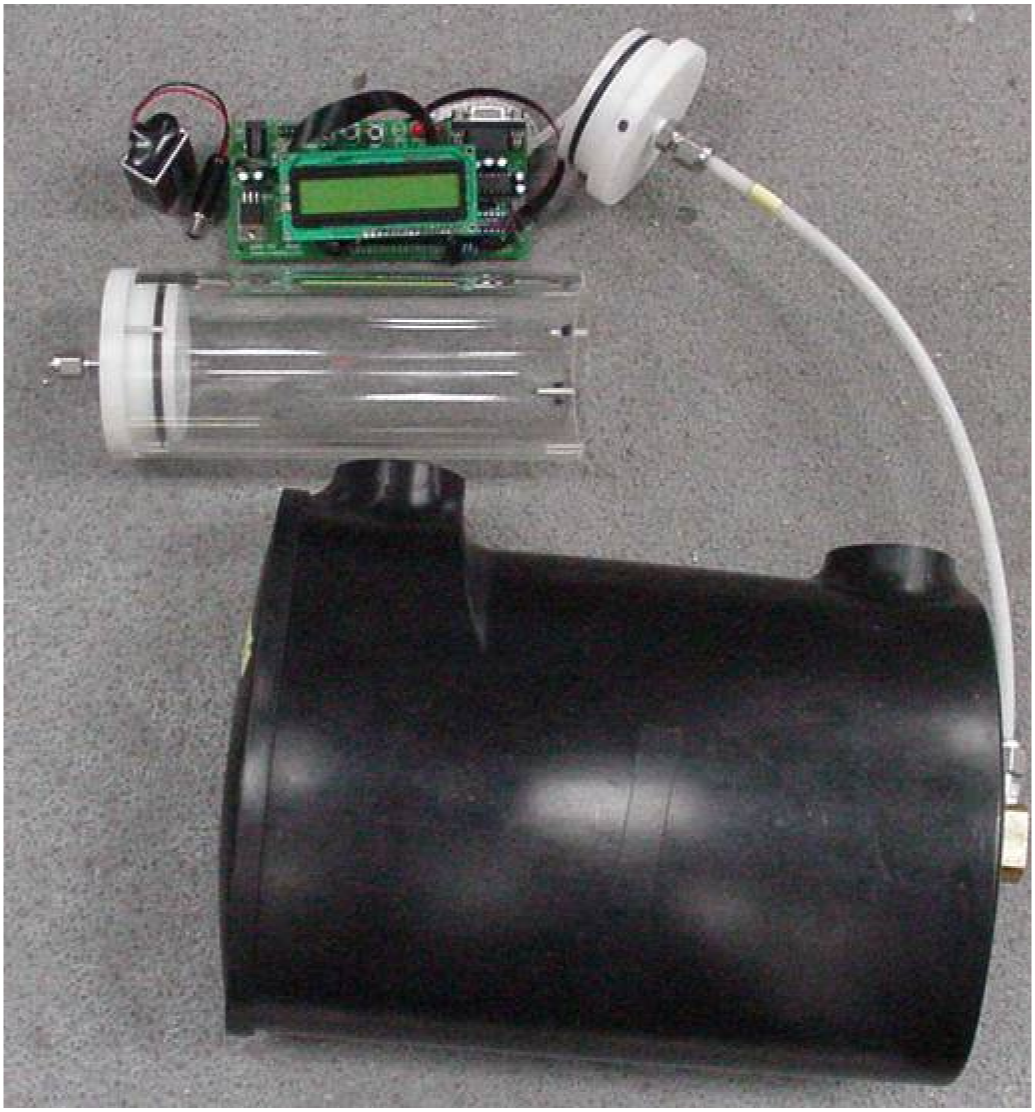

Figure 3. Photo of an instrumented scrubber with proof-of-concept gauge.

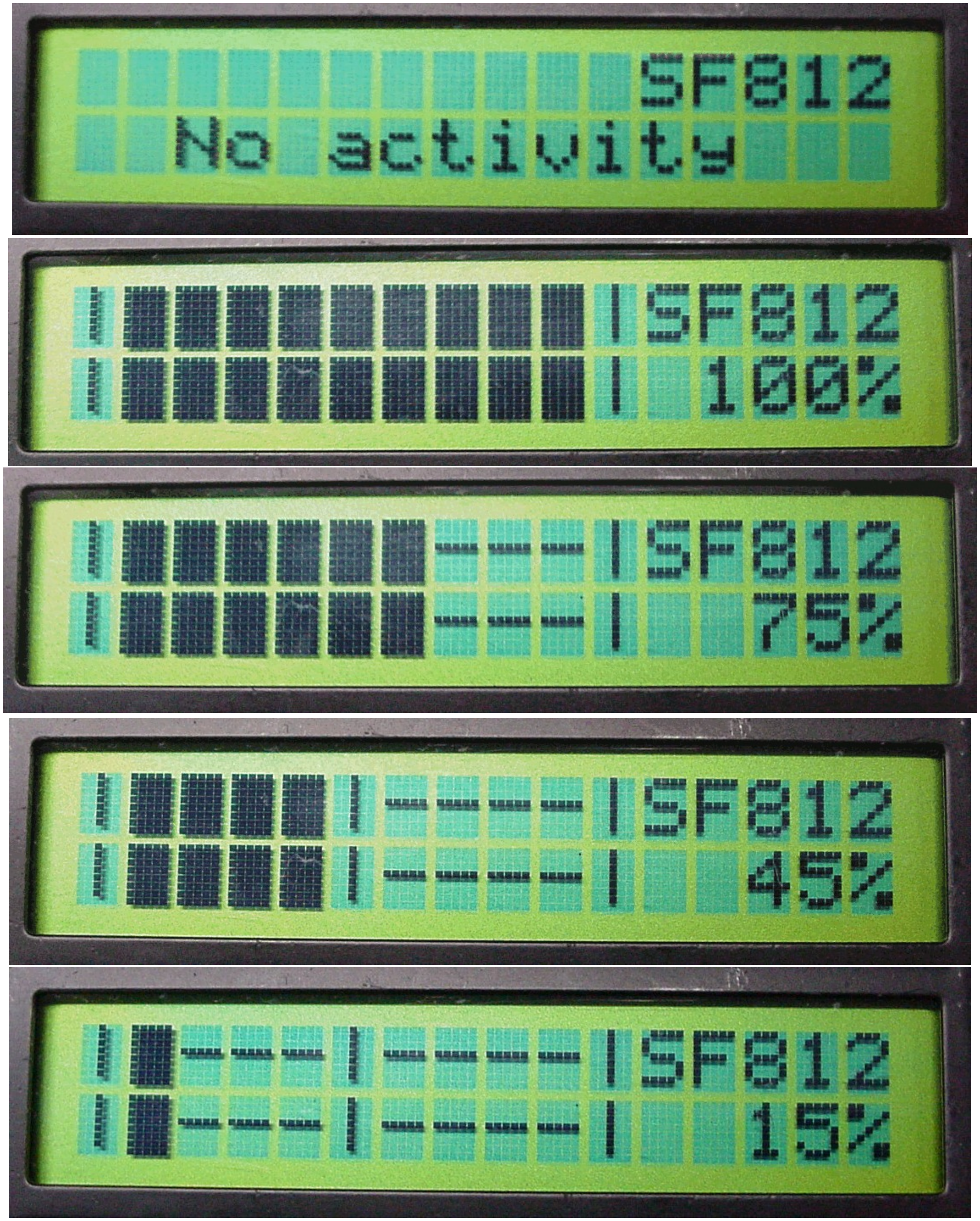

Figure 4. Examples of readings on the diver's display. SF812 indicates that Sofnolime 812 was used.

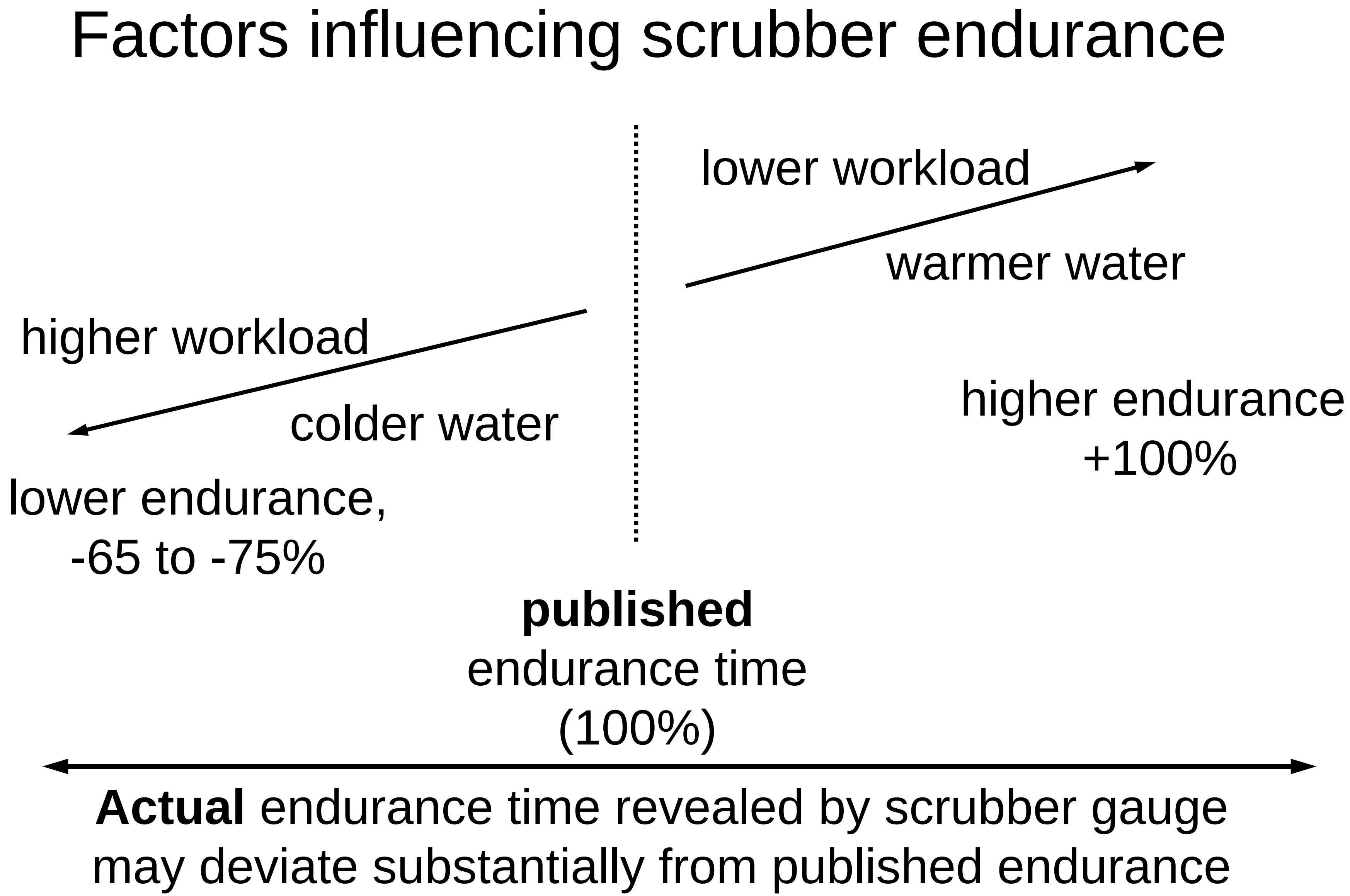

Figure 5. Factors influencing scrubber endurance.

CONCLUSION

Scrubber gauges will allow divers to safely extend dives based on real-time information on the scrubber performance. They will allow better planning, resulting in enhanced mission endurance, safety, flexibility, reduced cost, as well as increased diver confidence. A gauge will detect a lack of absorbent and may detect a flooded scrubber.

DISCUSSION

The actual scrubber endurance time varied dramatically. Standard endurance tests are performed at a minute ventilation of 40 L/min and a CO_2 injection rate of 1.6 L/min. However, cold water and higher workloads can reduce the endurance time by 65 to 75% (Figure 5). On the other hand, warm water or low workloads can extend the duration by 100 to 200%.

After extensive testing, a proof-of-concept unit was built and its performance demonstrated in both unmanned and manned dives.

The readings of remaining capacity were essentially independent of water temperature, depth and diver workload.

Readings of remaining capacity are provided already early in a dive.

Parts for the gauge are inexpensive. The temperature probes are stable and do not require any field calibration.

To build gauges for other models of rebreathers similar test need to be run to determine how the temperatures change and where probes need to be placed.

A gauge can detect a lack of absorbent and may detect a flooded scrubber.

REFERENCE

D. E. Warkander. Temperature-based estimation of remaining absorptive capacity of a gas absorber. U.S. Patent 6,618,687, assigned to the United States of America, as represented by the Secretary of the Navy, Washington, DC, 2003.

ACKNOWLEDGMENT
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