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ANALYSIS OF GASES PRODUCED BY THREE UNDERWATER CUTTING DEVICES

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ABSTRACT

The gas produced during underwater testing of 3 cutting systems was collected and analyzed to assess the explosion hazard related to the 3 processes. The underwater plasma cutting system produced up to 6% H_2, while the UK cutting rod produced up to 95% H_2. As the lower flammable/explosive limits of H_2 in air are 4%, H_2 safety issues are potentially related to using both these cutting processes. However, the explosive risk associated with the plasma cutting system appears much lower than that with the UK cutting rod, due to the substantially lower concentration of H_2 generated. The Broco cutting rod produced more than 90% O_2, an amount of O_2 associated with this cutting process that has long been recognized as a high risk factor. Unfortunately, the detection of up to 3.6% H_2 in the system check casts some concern on the reliability of the samples drawn during the actual cutting tests.

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INTRODUCTION

Underwater cutting has long been recognized as a hazardous task that has injured or killed divers. The current cutting method commonly used by the U.S. Navy uses a Broco cutting electrode with an oxygen (O_2) source for ignition and cutting, a device that produces large volumes of explosive gas. For these reasons, Naval Sea Systems Command (NAVSEA 00C5) is interested in identifying alternative, safer methods for underwater cutting.

In January 2003, NAVSEA 00C5 tasked the Navy Experimental Diving Unit (NEDU) to examine the gas composition produced by various types of underwater cutting equipment and assess the explosion hazards related to the evolved gas. Along with this task, we provided technical direction as well as gas sampling cylinders for collecting the gas during the cutting tests.

METHODS

CUTTING TESTING

NAVSEA 00C5 contracted Phoenix International (Morgan City, LA) to evaluate the performance of the following 3 underwater cutting processes (ensuing information is from Phoenix International) in its underwater test tank:

1. Plasma Cutting System manufactured by Thermal Dynamics Corp. (West Lebanon, NH). Model: Pak 44 Plasma Cutting System. This system creates a plasma gas by combining an electrical current with an inert gas (N_2); a secondary gas (CO_2) is used to flush the molten metal away from the cutting path.

2. Broco Underwater Ultrathermic Cutting System (commonly referred to as Broco cutting rod) manufactured by Aqua Air Industries, Inc. (Harvey, LA). Model: BR-22 Torch, HVR-4400 Regulator. This system delivers O_2, ignited by an electrical current, through the core of a rod.

3. UK Underwater Cutting System (new), developed by Jones Marine (London, UK). Model: Portland Technologies e-Rod cutting electrodes. This system generates an electrical arc through a standard welding torch.

Before collecting and testing any gas, we discussed the experimental approach with personnel at Phoenix International and offered suggestions to ensure reliable sampling. These suggestions included:

1. using clean hardware, preferably of metal, and avoiding soft material (e.g., plastic tubing) in constructing the gas sampling setup;

2. purging the system adequately during each test before conducting actual sampling;

3. taking triplicate samples during each test to allow repeated analysis, in accordance with good analytical practices, to confirm sampling reliability (Multiple samples would also provide extra gas for analysis, as pressure during cutting tests was expected to be ~1 atmospheres absolute [ATA] at the point of sample collection.); and

4. conducting system checks by flushing the system with clean gas and taking gas samples from the test setup when no cutting device was being used.

Phoenix International then wrote a final test plan, and we sent 12 evacuated, high-purity gas sampling cylinders to the company before testing started. Phoenix International personnel conducted all test procedures, including collection of gas samples. To evaluate the performance of the 3 cutting systems, the testing measured variables such as cutting times, cutting lengths, and amounts of rod used and gas produced. Performance results will be reported separately by Phoenix International.

During the actual test, a diver working ~5 feet beneath the surface of the underwater test tank used one of the 3 cutting methods to cut a 5/8-inch steel plate. The gas produced during each cutting process was collected in a hood (< 0.5 ft^3 gas-collection volume) made of Lexan and mounted in the test tank over the cutting area, and was routed to the surface through metal tubing and collected in the sample cylinders. Each test was begun with the hood completely filled with water. The cutting was then started, and the gas that was produced was allowed to completely displace the water and purge the sampling tubing through the sampling valve on the surface. This purging was then repeated by refilling the hood with water and allowing gas to flow through the collection tubing a second time. This purging was repeated a third time, at which time the cylinders were individually attached to the sampling valve on the surface to take triplicate samples. After the 3 cutting procedures had been tested, the hood was placed in a water barrel at the surface and filled with commercial grade N_2 to allow a system check to be made. A ~20-foot high-pressure hose was used to deliver the N_2 to the water barrel setup. Purging and sampling procedures were similar to those used for the cutting tests.

The test schedule was as given:

27 Jan 2003
1500 — UK cutting system

29 Jan 2003
1000 — Plasma cutting system
1500 — Broco cutting system
1530 — System check

GAS ANALYSIS

Before analysis began, the sample cylinders were vented to the atmosphere and then backfilled to 30 psig with zero grade N_2 to produce sufficient amounts of gas under pressure to facilitate loading the gas chromatographs. Other sample cylinders that had been filled with calibration gas standards were backfilled in identical fashion to confirm the dilutional ratio. All gas concentrations reported in the table (see RESULTS AND DISCUSSION) were corrected for this dilutional procedure.

Two different gas chromatography (GC) systems with molecular sieve columns and thermal conductivity detectors — one system using helium as the GC carrier gas and the other using argon — measured O_2, hydrogen (H_2), and N_2 levels. Gas chromatography coupled to a methanizer was used to measure CO_2 and carbon monoxide (CO).

Volatile organic compounds (VOCs) were analyzed by GC configured with flame ionization detectors with 2 different columns supplied by Supelco (Bellefonte, PA): 1) a 10-ft long, 1/8-inch stainless steel packed column, 3% SP-1500 on 80/120 Carbopack B, and 2) a 60-m long, 0.53-mm id, wide bore glass capillary column, Supelcowax 10, 1.0 micron film. These columns allowed detection of a wide range of VOCs below the 0.1 ppm level. We did not perform detailed characterizations of the VOCs with our GC/mass spectrometer: this work focused on explosive risk, and the observed VOC levels were considered well below those meriting concern. Primary gravimetric standards were used to quantify results, although the high levels of some components in some of the samples were well above the levels in our standards. This difference between sample and calibration concentrations was unavoidable, as the selection of gas standards before analysis was partly based on a guess about the expected sample composition. Consequently, extrapolation was necessary for some of the quantitation; this extrapolation affected the level of uncertainty associated with our reported values, as indicated in RESULTS AND DISCUSSION.

RESULTS AND DISCUSSION

Gas analysis results are given in the table below. The range in concentrations represents differences among the triplicate cylinders. All cylinders were not analyzed for all components, however, partly because adequate gas was unavailable. For these reasons, when the percentages are added together (e.g., for the UK cutting rod), they may exceed 100%.

GAS ANALYSIS RESULTS

	Plasma Cutting System	Broco Cutting Rod	UK Cutting Rod	System Check
O_2	0.1%	**88–93%**	0.5%	0.2%
CO_2	1.5%	1.2%	2.8%	445 ppm
CO	3.9%	0.2%	5.1%	6 ppm
H_2	**5–6%**	0.5%	**75–95%**	0–3.6%
Methane	3 ppm	15 ppm	0.1%	1.7 ppm
VOCs	~25 ppm	~30 ppm	~0.2%	~10 ppm
Balance	N_2	N_2	N_2	N_2

Accuracy for analysis of O_2, CO_2, and H_2 is estimated at ±2% relative, but greater uncertainty should be expected for H_2 > 10%. Accuracy for CO is estimated at ±2 ppm, except for CO > 100 ppm. Accuracy for methane and VOCs is ±20% relative, except for levels > 100 ppm. VOCs exclude methane.

The detection of up to 3.6% H_2 in the system check suggests that some sample gas carried over from previous testing, although the Broco test immediately preceding the system check did not produce substantial H_2. This result from the system check was discussed in detail with Phoenix International, and no reason for the anomaly could be determined. Unfortunately, the presence of H_2 in the system check raises some concern about the reliability of the samples drawn during the actual cutting tests.

The underwater plasma cutting system produced up to 6% H_2 along with 2% CO_2 and 4% CO. The UK cutting rod produced up to 95% H_2 as well as 3% CO_2, 5% CO, 0.1% methane, and 0.2% VOCs. For comparison, the Institute of Naval Medicine has recently reported that up to 8% of the lower explosive limit (LEL) of H_2 (or ~0.3% H_2) was detected with multigas monitors during underwater cutting with a Goodwin Air Plasma arc cutter.[1] As the lower flammable/explosive limits of H_2 (in air) are 4% and those of methane (in air) are 5%, potential H_2 safety issues appear to be related to using the underwater plasma cutting system and the UK cutting rod if the gas that is produced collects in pockets and an O_2 source such as air is present. However, the explosive risk associated with the plasma cutting system appears much lower than that with the UK cutting rod because of the plasma cutting's lower concentration of H_2. The Broco cutting rod produced more than 90% O_2, along with 1% CO_2. That large amount of O_2 associated with the Broco cutting rod has long been recognized as a high risk.

REFERENCE

1. P.J.T. Nicolson, S. Moore, J. Holmes, and R. Shayer. Exposure to hazardous substances and noise during surface and submerged air plasma arc cutting trials at Horsea Island. Institute of Naval Medicine Report No. 2001.016, 2001.