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The WET Buoyancy Engine

Controlling Buoyancy via Electrochemistry

Colin G. Cameron

Defence R&D Canada – Atlantic

Technical Memorandum
DRDC Atlantic TM 2005-214
October 2005

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Abstract

Technologies such as stealth buoys and underwater gliders need to modify their own buoyancy in order to operate. Strategies such as pumping fluid are typically used to change the device's net volume. This in turn requires a mechanically sophisticated (and consequently expensive) apparatus. This document introduces the concept of a buoyancy engine that exploits the enormous volume and pressure changes accompanying the reversible electrochemical interconversion of water to hydrogen and oxygen gases. Named the Water Electrolytic Transformation (WET) buoyancy engine, this device promises to deliver a new, efficient, and very inexpensive means to control buoyancy in remote sensing and surveillance devices.

Résumé

Les technologies comme les bouées furtives et les planeurs sous-marins doivent modifier leur flottabilité afin de fonctionner. Des stratégies comme le pompage de fluide sont habituellement utilisées pour changer le volume net du dispositif. Cela nécessite un dispositif sophistiqué du point de vue mécanique ; cette sophistication le rend coûteux. Le présent document introduit le concept d'un moteur qui exploite les énormes changements de volume et de pression qui accompagnent l'interconversion électrochimique réversible de l'eau en hydrogène gazeux et en oxygène gazeux. Ce dispositif pourrait s'avérer un moyen nouveau, efficace et très peu coûteux de contrôler la flottabilité des dispositifs de surveillance et de détection éloignés.

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Executive summary

The WET Buoyancy Engine: Controlling Buoyancy *via* Electrochemistry

Colin G. Cameron; DRDC Atlantic TM 2005-214; Defence R&D Canada – Atlantic; October 2005.

Background: Technologies such as stealth buoys and underwater gliders need to modify their own buoyancy in order to operate. Strategies such as pumping fluid are typically used to change the device's net volume. This in turn requires a mechanically sophisticated apparatus, increasing the cost of the vehicle while diminishing its reliability.

Principal results: This document introduces the concept of a buoyancy engine that exploits the enormous volume and pressure changes accompanying the reversible electrochemical interconversion of water to hydrogen and oxygen gases. The key concepts are described and illustrated with hypothetical scenarios for stealth buoys and design ideas for underwater gliders.

Significance of results: The proposed new technology, the Water Electrolytic Transformation (WET) buoyancy engine, promises to deliver a new, efficient, and very inexpensive means to control buoyancy in remote sensing and surveillance equipment. This in turn will lead to the production of inexpensive, disposable devices for numerous applications, such as the monitoring of shipping activity to early warning sensors for force protection in potentially hostile harbours. This buoyancy engine boasts the additional advantage of interfacing well with environmental energy harvesting concepts.

Future work: The next stage of development will be the fabrication of small scale engines in the laboratory for proof-of-concept purposes. Such work will clarify the operational benefits of various design features (such as single *vs.* double compartment) for specific applications. Subsequent work will see a scale-up to demonstrate a WET buoyancy engine in a conventional buoy housing as well as the construction of small test gliders.

Sommaire

The WET Buoyancy Engine: Controlling Buoyancy *via* Electrochemistry

Colin G. Cameron ; DRDC Atlantic TM 2005-214 ; R & D pour la défense Canada – Atlantique ; octobre 2005.

Introduction : Les technologies comme les bouées furtives et les planeurs sous-marins doivent modifier leur flottabilité afin de fonctionner. Des stratégies comme le pompage de fluide sont habituellement utilisées pour changer le volume net du dispositif. Cela nécessite un dispositif sophistiqué du point de vue mécanique ; cette sophistication augmente le coût du véhicule tout en diminuant sa fiabilité.

Résults principaux : Le présent document introduit le concept d'un moteur qui exploite les changements énormes en matière de volume et de pression qui accompagnent l'interconversion électrochimique réversible de l'eau en hydrogène gazeux et en oxygène gazeux. Les concepts-clés sont décrits et illustrés avec des scénarios hypothétiques pour les bouées furtives et des idées de conception pour les planeurs sous-marins.

Portée des résultats : Cette nouvelle technologie proposée sera vraisemblablement un moyen nouveau, efficace et très peu coûteux de contrôler la flottabilité de l'équipement de surveillance et de détection éloigné. Cela conduira à la production de dispositifs peu coûteux et jetables pour de nombreuses applications allant de la surveillance d'activités maritimes aux capteurs d'avertissement à l'avance servant à la protection dans les ports potentiellement hostiles. Ce moteur a aussi l'avantage de bien se marier avec les concepts d'économie d'énergie.

Recherches futures : La prochaine étape du développement sera la fabrication de moteurs à petite échelle dans le laboratoire à des fins de validation de concept. Un tel travail clarifiera les bénéfices d'exploitation de diverses caractéristiques de conception comme le recours à un compartiment simple ou à un compartiment double pour des applications spécifiques. Le travail subséquent consistera à mettre à l'échelle un moteur dans une bouée classique ainsi que de construire de petits planeurs d'essai.

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1 Buoyancy controlled vehicles

To change its buoyancy, any underwater vehicle must necessarily change its density. Since it is not practical to change mass, a net change in volume is needed. Typically, this volume change is accomplished by pumping fluid to and from bladders or tanks. This document introduces an alternative electrochemical approach, named the Water Electrolytic Transformation (WET) buoyancy engine. In order to illustrate potential applications for this new engine, this document will focus on two autonomous underwater devices that depend on variable buoyancy for the operation, and it will be shown that the WET buoyancy engine could serve as a practical replacement for current technology.

1.1 Stealth buoys

Stealth buoys are surveillance devices developed by DRDC Atlantic [1] in conjunction with Seimac. In essence, these buoys record data while they lie on the ocean floor where they are virtually undetectable and are less prone to drifting problems. When it becomes necessary to notify its deployer, the buoy inflates an elastic collar and rises to the surface in order to transmit its data to some receiving station. It then retracts the collar and descends to the bottom where it gathers new data. These buoys have obvious military applications such as tracking hostile ships and submarines, but also civilian applications such as detection of smuggling and monitoring marine life.

1.2 Underwater gliders

Underwater gliders are autonomous submarine vehicles that direct vertical force (buoyancy) to horizontal translation using wings. These devices have been showing promise in recent years as a means of collecting oceanographic data inexpensively [2]. There also exists the military potential for using fleets of gliders for autonomous remote sensing and surveillance over a large patrol area. DRDC Atlantic has already started experiments with the Slocum glider.

2 The WET buoyancy engine

2.1 Electrochemistry

Electrolytic phase transformation was first reported several years ago as an alternative materials-based actuation strategy [3–5]. This technology exploits the enormous pressure and volume changes that accompany the electrochemical interconversion between liquid water and hydrogen and oxygen gases:

$$energy + 2\,\mathrm{H_2O}\,(l) \rightleftharpoons 2\,\mathrm{H_2}\,(g) + \mathrm{O_2}\,(g) \tag{1}$$

Expressed as the two constituent half-cell reactions, (one occurring at each of two electrodes)

$$\begin{aligned} 2\,\mathrm{H_2O}\,(l) &\rightleftharpoons 4\,\mathrm{H}^+\,(aq) + \mathrm{O_2}\,(g) + 4\,e^- \quad (2) \\ 4\,\mathrm{H}^+\,(aq) + 4\,e^- &\rightleftharpoons 2\,\mathrm{H_2}\,(g) \quad (3) \end{aligned}$$

This implies that two molecules of water may be converted to three molecules of gas, reversibly, with an accompanying flow of four electrons through an external circuit. This reaction occurs with a thermodynamic potential of 1.23 V [6]. The reversibility of the reaction should be emphasized; the generation of gas requires the input of electrical energy, but the recombination is spontaneous and will produce electrical energy under particular circumstances, *i.e.*, a fuel cell.

The behaviour of the generated gases can be well described by the ideal gas law:

$$PV = n_g RT \quad (4)$$

where P and V are the pressure and volume of n_g moles of gas at temperature T, and $R = 8.3145\ \mathrm{m^3\,Pa\,mol^{-1}\,K^{-1}}$ is the gas constant.

The volume V_w of n_w moles of pure water (density $\rho = 1.00$ g/mL and molecular weight $M_w \approx 18$ g/mol) is easily calculated:

$$V_w = n_w \times M_w/\rho \quad (5)$$

The reaction stoichiometry of Equation 1 indicates that 3 moles of gas will arise from the electrolysis of 2 moles of water. Invoking the ideal gas law (Equation 4), the volume of gas V_g resulting from the electrolysis of n_w moles of water is:

$$V_g = (3/2) n_w RT/P \quad (6)$$

The engine's buoyancy arises from the weight of water the gas can displace. Since $V_g \gg V_w$ ($V_g/V_w \approx 1360$ at ambient temperature and pressure), the volume of water consumed can be neglected (and this may not be a consideration anyway, depending on the device configuration). Keeping in mind that the total pressure experienced by the engine is equal to the sum of atmospheric and water depth pressures (P_{atm} and P_{water} respectively) and that four moles of electrons n_e are required to create three moles of gas (see Equations 2 and 3), an expression relating the buoyant force B of a WET buoyancy engine device with electrical charge Q may be derived from Equation 6 and Faraday's constant $F = 9.54 \times 10^4\ \mathrm{C\,mol^{-1}}$:

$$\begin{aligned} B &\approx V_g \rho / g \quad (7) \\ &= \frac{(3/2) n_w RT\rho}{(P_{atm} + P_{water}) g} \quad (8) \\ &= \frac{(3/4) n_e RT\rho}{(P_{atm} + P_{water}) g} \quad (9) \\ &= \frac{(3/4) QRT\rho}{(P_{atm} + P_{water}) Fg} \quad (10) \end{aligned}$$

For simplicity, force due to gravity $g = 9.8$ N kg^{-1} may be omitted to express buoyancy in, for example, grams-force instead of Newtons.

2.2 Operation

2.2.1 Energy requirements

Since its operation is governed by the ideal gas law (Equation 4), the WET buoyancy engine response is pressure and temperature dependent. At greater depths and colder temperatures, more electrical energy is required to reach a given buoyancy; the buoyancy will increase as a WET buoyancy engine equipped vehicle ascends. Methods to govern this condition will be considered later in section 3.2.

Table 1 outlines the relationship between electrical energy at varying depths of sea water ($\rho = 1.03$ g ml^{-1}) to reach an arbitrary 1 g of buoyant force. This assumes a driving voltage of 1.5 V, a water temperature of 10 °C, and a pressure increase of 10.08 kPa m^{-1}. For reference, a rechargeable 1.2 V 9500 mAh NiMH D-cell contains around 34.2 kC of charge and approximately 41 kJ of energy.

2.2.2 Cell design

The electrolysis cell is simple in design. A simple two-electrode configuration is satisfactory; there is no need for a precise measurement of electrode potentials, hence a three-electrode cell is not required. Three fundamental design concepts are illustrated in Figures 1 and 2 in order of increasing complexity. The key issues are: rigid compartment *vs.* bladder, and mixed *vs.* separated gases. The issue of gas separation will be revisited in section 2.3. Electrodes made from platinum or palladium would offer superior electrochemical kinetics for the electrolysis reaction. However, less expensive materials (*e.g.*, stainless steel) could be used with satisfactory results.

The fundamental operation of these devices is straightforward, as illustrated in Figure 1.

Table 1: *Theoretical charge and energy requirements per gram of buoyant force at various depths, and the corresponding buoyant force that can be achieved by the energy of single D-cell*

Depth (m)	Pressure (Pa)	Charge (C)	Energy (J)	Buoyancy per D-cell (g)
0	1.01×10^5	5.28	7.93	5.17×10^3
1	1.11×10^5	5.81	8.71	4.70×10^3
10	2.02×10^5	10.5	15.8	2.59×10^3
100	1.11×10^6	57.9	86.8	4.72×10^2
1000	1.02×10^7	540	811	5.06×10^1

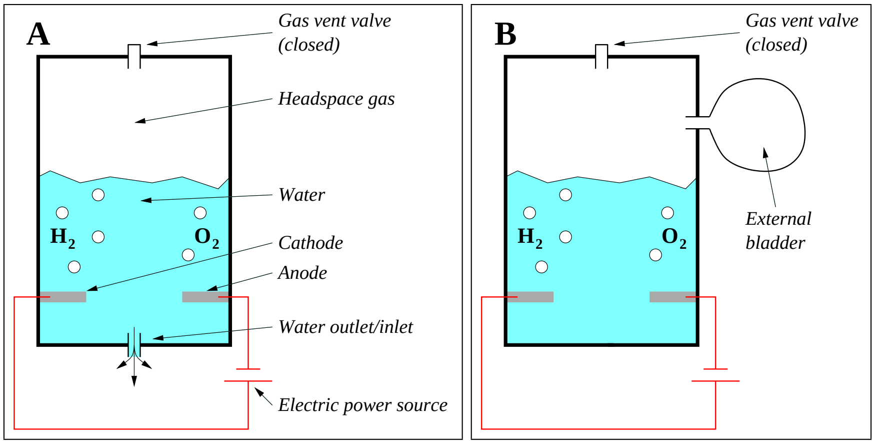

Figure 1: *Overview of a single compartment WET buoyancy engine. Increased buoyancy is achieved by (a) using generated gases to expel water, or (b) inflation of a gas bladder.*

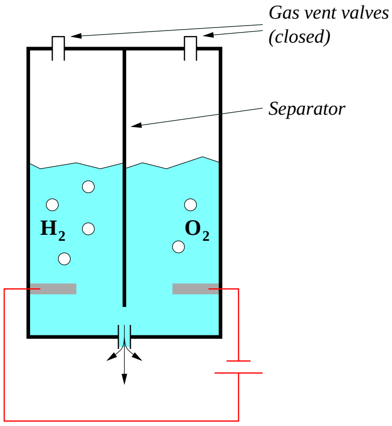

Figure 2: *Double compartment WET buoyancy engine. A solid barrier separates hydrogen and oxygen gases, but an opening allows passage of ions and equilibration of internal pressures.*

The pressure of gases resulting from the application of electrical current can be employed to change the density of the device either through expelling water from the system, or through inflating a float bladder. In the former case, sea water would be used as the electrolysis medium. In the latter, only on-board water could be used (this might be useful in scenarios where salt water is undesirable, or if a low solution pH is desired). After the WET buoyancy engine powered vehicle has surfaced, resubmerging is easily done by simply venting the gases. A slightly more sophisticated design involves a physical barrier separating the hydrogen and oxygen gases, as shown in Figure 2. This configuration is somewhat safer, avoiding a potentially reactive combination of gases. The separation leads to the possibility of recapturing the chemical energy in a controlled manner. There must be some provision of ionic transport between the two compartments. This can be a simple hole, a porous material (*e.g.*, fritted glass) or a membrane.

2.3 Energy recapture

The electrochemical reaction of hydrogen and oxygen forms the basis of the hydrogen fuel cell, a concept of enormous economic importance. Already prototype vehicles based on Proton Exchange Membrane (PEM) fuel cells are being demonstrated.

The reaction in question is the same as presented earlier (see Equation 1), but in the direction opposite to electrolysis. The reaction is exothermic and spontaneous on a catalyst surface. By separating the half-reactions, it is possible to recover the chemical energy in the form of electricity. Figure 3a illustrates the PEM fuel cell. At the heart of this device lies a membrane that permits the passage of protons only. This serves to keep the electrochemical half-reactions separated. Hydrogen arriving at the anode (usually made of platinum or a platinum alloy) and is oxidized to free protons. The protons pass through the membrane, while the associated electrons are forced to pass through an external electrical circuit. The electron then reach the cathode (often containing platinum or platinum-ruthenium alloys), where they combine with the protons and oxygen gas, forming water. The reaction continues spontaneously until the fuel is exhausted or the external electrical circuit is interrupted.

The same cell can be operated in reverse, Figure 3b, which is the familiar electrolysis reaction. Such a device operated both directions is a called a regenerative fuel cell (RFC) [7–9], and is a useful means of storing energy. NASA has used RFC technology in record-breaking solar-powered high-altitude autonomous aircraft [10]; RFC units store surplus energy collected in daylight for night operation. The theoretical cycle efficiency of charging and discharging a RFC is approximately 80% [8], although the practical achievable efficiencies are somewhat less.

The interconversion of gases and electrical energy has previously been demonstrated as an actuation strategy [3–5]. Here, the interconversion can be exploited to control buoyancy reversibly and precisely. Being based on the same principles as RFCs, the WET buoyancy engine promises highly efficient operation, since part of the energy expended during the gas generation stage can be recovered in the reverse step. Furthermore, since this engine is essentially an energy storage device, it is very well suited to operating in conjunction with environmental energy harvesting schemes.

3 Concepts for WET buoyancy engine applications

The WET buoyancy engine stands out for its simplicity. The lack of moving parts (other than a vent valve if so configured) implies operational robustness and inexpensive assembly; a working engine can be built for dollars. This implies that WET buoyancy engine is

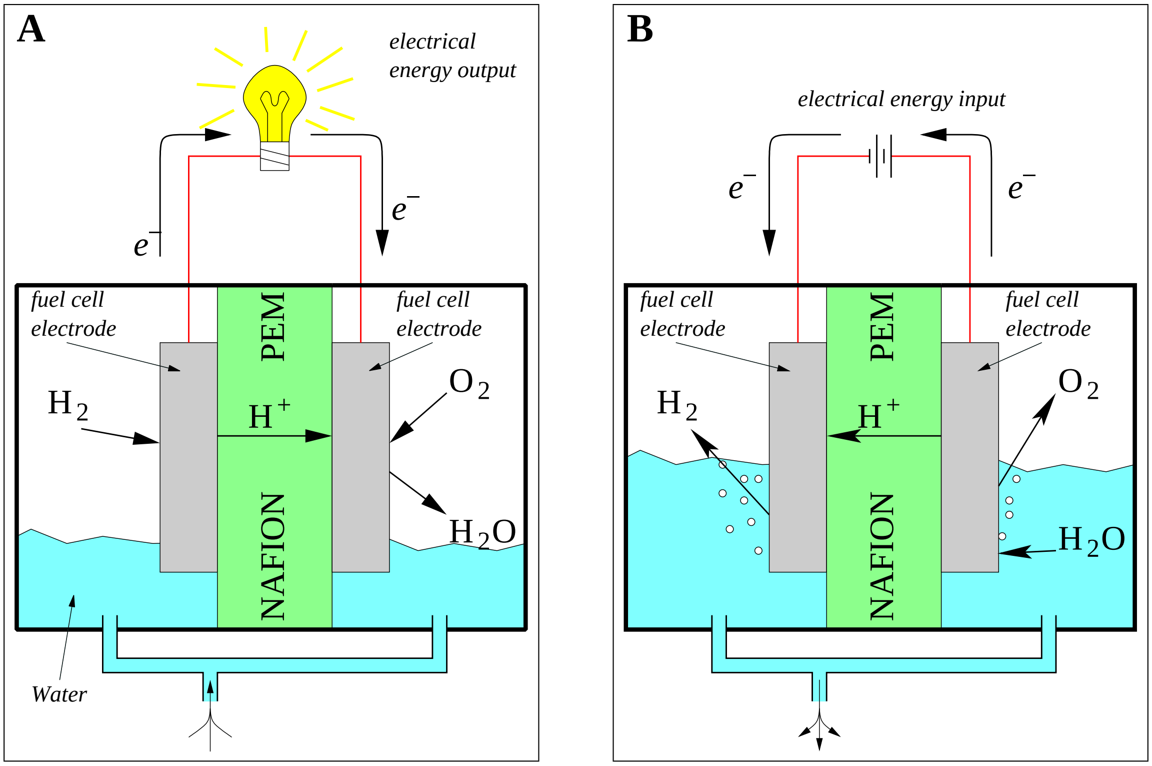

Figure 3: *Regenerative fuel cell operation. (a) Schematic of a typical proton exchange membrane fuel cell. The hydrogen and oxygen gases are physically separated by a membrane that allows the passage of protons only. Water is produced and electric power is generated. (b) Application of external voltage drives the cell in the reverse direction, resulting in electrolysis.*

ideal for autonomous and disposable applications.

3.1 Stealth buoys

WET buoyancy engine technology is well suited to driving inexpensive stealth buoys. A buoy deployed on the ocean bed could be made positively buoyant through the electrolysis reaction. After the buoy has completed its radio transmission at the surface, venting the gas would cause the device to sink once again. As an example, using the information from Table 1, a stealth buoy lying on the sea bed at a depth of 100 m and needing 20 g of buoyant force to start its ascent[1] would need roughly 1.7 kJ of energy input. A single D-cell could provide sufficient energy to power 24 cycles. A regenerative system could improve this figure; reacting the gases in a RFC configuration would recoup a significant fraction of the energy. The current work on 11 kg A-size sonobuoys suggests that a minimum of 1.2 L of water displacement should be effected to left the device off the bottom. From a 100 m

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[1] Because of the expansion of the gases, at the surface this would translate to around 220 g of buoyancy

deployment, the energy content of 2.5 D-cells would be expended per ascent. Realistically, an energy recapture scheme should lower this to between one (representing 60% recapture) and two (20% recapture) D-cells.

Alternatively, an energy harvesting scheme could be used to drive the electrolysis reaction, allowing indefinite operation of the buoyancy engine. A simple turbine attached to a small DC generator would suffice to convert the kinetic energy of water due to tidal flow. For a turbine with rotor diameter r in water flowing with a current v, it is easy to derive an expression for kinetic energy E per unit time t:

$$E/t = (1/2)\rho\pi r^2 v^3 \tag{11}$$

As an example using real-world parameters, at the time of this writing (early July 2005) the predicted peak tidal current flow in Halifax harbour [11] ranges from around 0.34 m/s (0.22 m/s average) under the MacDonald bridge to around 0.10 m/s (0.064 m/s average) in the vicinity of the anchorage between George's and McNab's islands (an area commonly used by visiting aircraft carriers). Assuming a generator with a turbine around the size of a compact disc (6 cm radius), in one 24-hour period over 1.6 kJ could be collected from tidal flow under the MacDonald bridge. Assuming an overall conversion efficiency of only 30%, such a device could provide 20 g of buoyant lift to a stealth buoy sitting on the bottom (around 20 m deep) every 24 hours.

3.2 Underwater gliders

Underwater gliders travel through the water by changing their buoyancy to generate net upwards or downwards force accordingly. The force is translated to horizontal motion by the glider's "wings". The buoyancy change is accomplished by the glider changing its internal volume typically on the order of 100 cm^3 via the pumping of fluids, and attitude is controlled by shifting internal weights (usually the battery tray). At least three gliders are commercially available: Seaglider [12], Spray [13], and Slocum (Webb Research) [2]. Key parameters from each are summarized in Table 2. Two parameters are worth considering: efficiency and cost.

First, the energy consumption in the conventional gliders to reach a certain buoyancy is not strongly dependent on depth, since the same quantity of fluid will be pumped under all conditions. This is reflected in the poor efficiencies at shallower cycles. It can be concluded then that these gliders are inefficient for operations in other than deep sea conditions (notwithstanding, Slocum is already optimized for shallow operations). Consequently, they are ineffective for the littoral applications that would be most useful for surveillance and reconnaissance. The WET buoyancy engine consumes energy proportional to depth, and

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[2] A thermal Slocum has been proposed [14]. The vehicle exploits thermal gradients in the ocean to modulate buoyancy.

Table 2: *Summary of typical operational parameters for three underwater gliders from published [2] data.*

	SPRAY	SLOCUM	SEAGLIDER
total length (cm)	200	215	330
diameter (cm)	20	21	30
batteries	52 DD lithium	250 C Alkaline	81 D Lithium
energy (MJ)	13	8	10
efficiency	50%@1000m 20%@100m	50%@200m	40%@1000 8%@100m
max depth (m)	1500	200	1000
buoyancy (g)	125	230	130
range (km)	7,000	500	4,600
endurance (days)	330	20	200
price ($USD)	50,000	70,000	70,000
refuel cost ($USD)	2,850	675	1,375

are therefore more efficient in shallower waters. A glider propelled by a WET buoyancy engine would be ideal for military operations.

Second, the cost (and, presumably, reliability) of the vehicles is largely a reflection of their mechanical nature. Pumps to change buoyancy and screw motors to change centre of gravity add expense and complexity to the apparatus. The WET buoyancy engine has no moving parts. Buoyancy can be controlled by one cell. Pitch and roll can be controlled with two additional independent cells. Using regenerative cells, buoyancy, pitch, and roll (and thus yaw) can be controlled as a self-contained system, with “pumping” achieved by electrical means, as illustrated in Figure 4. In this arrangement, the battery can be thought of as a reservoir for the electricity-gas equivalency.

One further advantage of using RFC WET buoyancy engine units as shown in Figure 4 is that gas can be continuously reconsumed during the ascent in order to maintain constant buoyancy. Additionally, the cell open circuit voltage will be proportional to the gas pressure, in accordance with the Nernst equation [6]. Therefore, the RFC could serve as a redundant depth gauge.

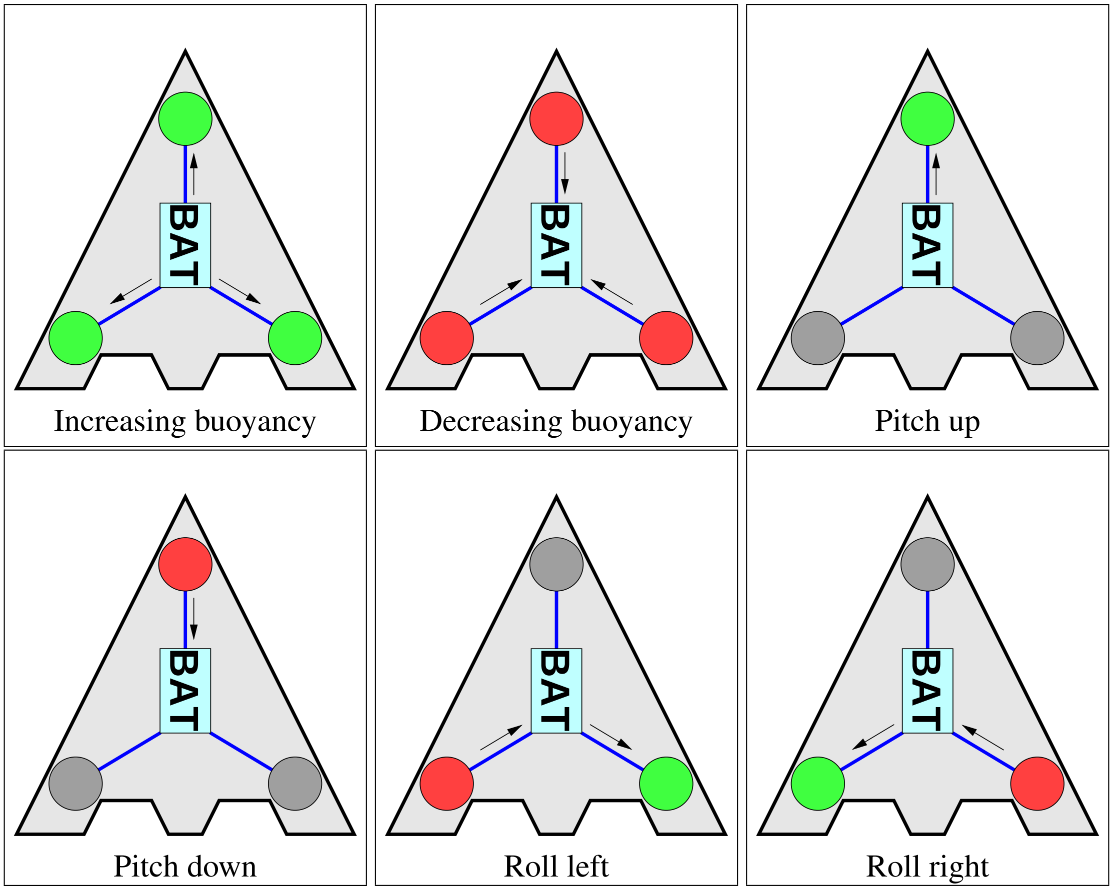

Figure 4: *Fundamental concepts in WET buoyancy engine gliders. One self-contained regenerative buoyancy unit (circle) is present in the nose and in each wing. Green indicates electrolysis, red indicates recombination, and grey circles are inactive. Arrows indicate the direction of power flow to or from the battery.*

4 Conclusion

Buoyancy control is a key element to the operation of autonomous underwater vehicles. Stealth buoys and underwater gliders cannot function without a means of increasing and decreasing their buoyancy, usually by means of pumping fluids.

The Water Electrolytic Transformation buoyancy engine exploits an electrochemical reaction to achieve buoyancy changes. This approach is very efficient, especially in depths associated with littoral waters, and is also silent. It uses no moving parts, and is consequently extremely reliable. It is also very inexpensive to construct and uses no toxic materials. Furthermore, it lends itself well to scaling, which indicates that much smaller devices could be deployed.

Because of their simplicity, WET buoyancy engines are an attractive replacement for the engines that currently drive stealth buoys and underwater gliders.

5 Acknowledgements

The ideas presented here arose from conversations with Jeffrey Smith of the Business Development Office, DRDC Atlantic.

6 Symbols and Abbreviations

DC	Direct current
PEM	Proton exchange membrane
RFC	Regenerative fuel cell
WET	Water electrolytic transformation

References

[1] Spotlight on S&T – May 2004: DRDC's Stealth Buoy Hailed as Future of Marine Surveillance (online), Defence R&D Canada, `http://www.drdc-rddc.gc.ca/newsevents/spotlight/0405_e.asp` (Access Date: July 2005).

[2] Rudnick, D., Davis, R., Eriksen, C., Fratantoni, D., and Perry, M. (2004), Underwater gliders for ocean research, *Marine Technology Society Journal*, 38, 73–84.

[3] Cameron, C. and Freund, M. (2002), Electrolytic actuators: Alternative, high-performance, material-based devices, *Proc. Natl. Acad. Sci. U.S.A.*, 99, 7827–7831.

[4] Cameron, C. and Freund, M. (2003), Reversible and efficient materials-based actuation by electrolytic phase transformation, *Chem. Eng. Technol.*, 26, 1007–1011.

[5] Cameron, C. G. and Freund, M. S. (2003), Electrolytic phase transformation actuators, *Proc. SPIE*, 4878, 14–20.

[6] Bard, A. J. and Faulkner, L. R. (2001), Electrochemical Methods, 2 ed, Wiley.

[7] Findl, E. and Klein, M. (1967), Electrolytically Regenerative Hydrogen / Oxygen Fuel Cell Battery, In *Regenerative EMF cells*, pp. 292–305, American Chemical Society.

[8] Barbir, F., Molter, T., and Dalton, L. (2005), Regenerative fuel cells for energy storage: Efficiency and weight trade-offs, *IEEE Aerosp. Electron. Syst. Mag.*, 20, 35–40.

[9] Mitlitsky, F., Weisberg, A. H., and Myers, B. (1999), Vehicular hydrogen storage using lightweight tanks (regenerative fuel cell systems), In *Proceedings of the 1999 U.S DOE Hydrogen Program Review*. NREL/CP-570-26938.

[10] NASA Dryden Flight Research Center (1998), Solar-powered Pathfinder-Plus hits new unofficial altitude record. Press Release 98-64. `http://www.nasa.gov/centers/dryden/news/NewsReleases/1998/98-64.html`.

[11] Ocean Science Division, Bedford Institute of Oceanography, Fisheries and Oceans Canada, WebTide Version 0.65. `http://www.mar.dfo-mpo.gc.ca/science/ocean/home.html`.

[12] Eriksen, C., Osse, T., Light, R., Wen, T., Lehman, T., Sabin, P., Ballard, J., and Chiodi, A. (2001), Seaglider: A long-range autonomous underwater vehicle for oceanographic research, *IEEE J. Ocean. Eng.*, 26, 424–436.

[13] Sherman, J., Davis, R., Owens, W., and Valdes, J. (2001), The autonomous underwater glider ”spray”, *IEEE J. Ocean. Eng.*, 26, 437–446.

[14] Webb, D., Simonetti, P., and Jones, C. (2001), SLOCUM: An underwater glider propelled by environmental energy, *IEEE J. Ocean. Eng.*, 26, 447–452.

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Technologies such as stealth buoys and underwater gliders need to modify their own buoyancy in order to operate. Strategies such as pumping fluid are typically used to change the device's net volume. This in turn requires a mechanically sophisticated (and consequently expensive) apparatus. This document introduces the concept of a buoyancy engine that exploits the enormous volume and pressure changes accompanying the reversible electrochemical interconversion of water to hydrogen and oxygen gases. Named the Water Electrolytic Transformation (WET) buoyancy engine, this device promises to deliver a new, efficient, and very inexpensive means to control buoyancy in remote sensing and surveillance devices.

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Buoyancy engine; stealth buoys; sonobuoy; underwater glider; water electrolytic transformation; WET

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