AUV/UUV Fuel Cell Propulsion Options

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***Abstract*- Low-temperature fuel cells offer the potential for long mission duration when coupled to a high-energy-density fuel in an auxiliary fuel tank. Candidate high-energy-density fuels include methanol, diesel, and jet fuels. However, all of these fuels must be reformed into hydrogen which is subsequently consumed by the fuel cell to generate electrical power. Thus, a fuel processor becomes a necessary component in the overall fuel cell system.**

I. INTRODUCTION

Fuel cells are a type of energy conversion technology: they convert fuels (most often hydrogen) into direct-current electricity. Fuel cells are inherently quiet as they have no moving parts (note that the balance-of-plant that supports a fuel cell will incorporate fans, pumps, etc, and these components are subject to wear and they are a source of noise). Functionally, fuel cells are similar to batteries (both convert a fuel and an oxidant into DC electricity). However, unlike batteries, fuel cells do not store fuel and oxidant internally and therefore will continue to produce electricity for as long as fuel and oxidant are supplied to the fuel cell. The potential advantages of replacing batteries with fuel cells to provide electrical power to undersea vehicles (manned and unmanned) are listed below:

- Increased power density
- Ease and speed of refueling
- Long mission duration

There are several different types of fuels cells, distinguished primarily by operating temperature. Proton-exchange-membrane fuel cells (PEMFCs) and alkaline fuel cells (AFCs) operate at temperatures less than 100°C; phosphoric-acid fuel cells (PAFCs) operate in the range of 180°C-220°C; molten-carbonate fuel cells (MCFCs) operate at about 500°C to 600°C; whereas solid-oxide fuel cells (SOFCs) operate at very high temperatures (typically 700°C to 1000°C). Only the low-temperature fuel cells (PEMFC and AFC) are suitable for use in small to mid-sized AUV and UUV applications.

Figure 1. A 1 kW PEMFC system showing the fuel processor at the lower right and the fuel cell stack at the left.

A typical fuel cell system, with its principle subsystems, is shown in Figure 1. The fuel cell stack converts hydrogen (fuel) and air (oxidant) into unregulated DC electricity. The fuel cell shown is an air-cooled PEMFC. Hydrogen is produced on demand by the fuel

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processor: as hydrogen is produced it is consumed by the fuel cell, so there is no requirement for hydrogen storage. The feedstock (or fuel) from which hydrogen is generated is methanol. The advantages of producing hydrogen on demand from a convenient liquid fuel such as methanol are described in more detail below. The unregulated DC electrical output from the fuel cell is converted to regulated (constant voltage) DC electricity by the on-board power electronics. The entire system is automated.

II. Discussion

The fuel cell system shown in Figure 1 is relatively compact in size (measuring 64 cm by 60 cm by 50 cm high). It is a silent 1 kW generator. The system will continue to generate 1 kW of regulated DC electrical power as long as fuel and air are supplied making fuel cells particularly attractive for long-duration missions. And this is where the advantages of a liquid fuel combined with a fuel cell become most apparent. The energy density of liquid fuels, including methanol, are much greater than the energy density of stored hydrogen.

But it is hydrogen that is required to operate the fuel cell stack, and so the correct comparison is the hydrogen-storage density of methanol versus other options. This is shown graphically in Figure 2.

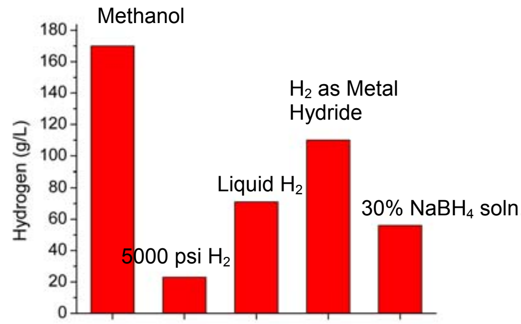

Figure 2. Comparative hydrogen volumetric storage capacities.

Methanol is a more effective hydrogen storage medium than are other common options, including metal hydrides and aqueous sodium borohydride solution. Moreover, methanol is a liquid that is easily handled and is compatible with most common materials. Therefore refueling with methanol is faster and more convenient than many other options (e.g., liquid H_2 and metal hydride storage).

A complete fuel cell power plant with fuel tank and stored oxidant can offer greater energy density than is achievable with batteries (Figure 3). The oxidant may be stored as compressed O_2, liquid O_2, or a chemical source such as a Group I/II metal peroxide or Group I/II metal superoxide. Worldwide availability and relative safety of compressed O_2 are likely to favor this as the preferred oxidant storage means except for those applications involving the largest of underwater vehicles (i.e., manned submarines).

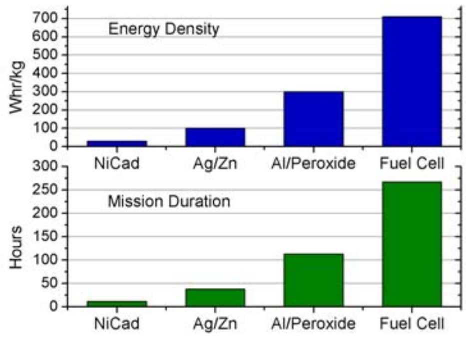

Figure 3. Comparative energy densities.

Mission duration is often limited by the available energy expressed as on-board battery capacity or, in the case of fuel cells, by the amount of stored fuel and oxidant. Figure 3 compares the mission duration for a hypothetical vehicle based on the following assumptions:

Basis: Batteries/Fuel Cell each weigh 158 kg
Assumes total load is 300W

Fuel Cell System:
• Fully integrated system
• 60 L methanol/water fuel
• 27 Nm^3 oxygen (at 3000 psi)
• Total weight = 158 kg

In the case of a fuel cell propulsion system, the mission duration is extended by simply storing more fuel and oxidant on the vessel. In the case of liquid fuels (methanol, diesel, jet fuels, etc.) the fuel can be stored in irregularly shaped portions of the vessel rather then using prime space. Since the "fixed" weight of the fuel cell system remains unchanged, the energy density of a fuel cell system including stored fuel and oxidant approaches the energy density of the combination of fuel plus oxidant at long mission duration. On the other hand, batteries are simply additive, meaning that the energy density remains the same for short and long mission duration.

III. Conclusions

Fuel cells are a class of energy conversion technology that generate DC electricity directly from the electrochemical reaction of a fuel (typically H_2) with an oxidant (typically O_2 from air). The energy efficiency of fuel cells can be relatively high because they are not subject to the limitations of the Carnot cycle. Overall system efficiencies of 25% to 35% (simple cycle) have been demonstrated starting with methanol.

Although additional development of fuel cell propulsion systems for underwater vehicles is needed, the potential advantages of this approach include:

- High effective energy density
- Long mission duration (days to weeks)
- Quiet operation
- Speed and ease of refueling

The range of power demand that can be met with fuel cell systems spans from watts to many kW, but it is likely that systems ranging from 100 W to 2 kW are best suited for near-term to mid-term applications. For long-duration missions, it is likely that fuel cell power plants using compact PEMFC technology and advanced methanol fuel processors can yield energy densities in excess of 500 W/kg and approach 1000 W/kg.